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DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 27

WORK DONE IN THE DIVISION OF CHEMISTRY AND PHYSICS
MAINLY DURING THE FISCAL YEAR 1884-'85

WASHINGTON
GOVERNMENT PRINTING OFFICE
1886

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ADVERTISEMENT.

[Bulletin No. 27.]

The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the Library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this Office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Mineral Resources and Dictionary of Altitudes, the Survey has no copies of any of its publications for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth and Sixth Annual Reports are in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, and VIII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt. U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

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The following are in press, viz:

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey. by Robert P. Whitfield. 1885. 4°. ix, 338 pp. 35 pl.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. —, — pp. 56 pl.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl.

XII. Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons.

The following are in preparation, viz.:

I. The Precious Metals, by Clarence King.

— Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

— Lake Bonneville, by G. K. Gilbert.

— Sauropoda, by Prof. O. C. Marsh.

— Stegosauria, by Prof. O. C. Marsh.

— Geology of the Quicksilver Deposits of the Pacific Slope, with atlas, by George F. Becker.

— The Penokee-Gogebic Iron-Bearing Series of North Wisconsin and Michigan, by Roland D. Irving

— Description of New Fossil Plants from the Dakota Group, by Leo Lesquereux.

— Younger Mesozoic Flora of Virginia, by William M. Fontaine.

— Report on the Denver Coal Basin, by Samuel F. Emmons.

— Report on Ten-Mile Mining District, Colorado, by Samuel F. Emmons.

— Report on Silver Cliff Mining District, by Samuel F. Emmons.

— Flora of the Dakota Group, by J. S. Newberry.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of Annual Reports or Monographs.

Each of these Bulletins will contain but one paper and will be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient sizes. To facilitate this, each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 27 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining value of troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South) 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. A Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary studies, by Charles Doolittle Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett, 1885. 8°. 135 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

15. On the Mesozoic and Cenozoic Paleontology of California, by Dr. C. A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the higher Devonian Faunas of Ontario County, New York, by J. M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 10 cents.

17. On the Development of Crystallization in the Igneous Rocks of Washoe, by Arnold Hague and J. P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Dr. C. A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.

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19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White, M. D. 1885. 8°. 25 pp. 5 pl. Price 5 cents.

23. The Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary Fossils and recent forms from American localities between Cape Hatteras and Cape Roque, including the Bermudas, by W. H. Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The Present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 82 pp. Price 10 cents.

26. Copper Smelting, by Henry M. Howe. 1885. 8°. 107 pp. Price 10 cents.

27. Work done in the division of Chemistry and Physics mainly during the fiscal year 1884-'85. 1886. 8°. 80 pp. Price 10 cents.

Numbers 1 to 6 of the Bulletins form Volume I; Numbers 7 to 14, Volume II; Numbers 15 to 23, Volume III; and Numbers 24 to 30, Volume IV. Volume V is not yet complete.

The following are in press, viz:

28. The Gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Md., by George H. Williams.

29. On the Fresh-water Invertebrates of the North American Jurassic, by Dr. C. A. White.

30. Second contribution to the studies on the Cambrian Faunas of North America, by Charles D. Walcott.

31. A systematic review of our present knowledge of fossil insects, including Myriapods and Arachnids, by Samuel H. Scudder.

32. Report of the Mineral Springs of the United States, by Albert C. Peale.

33. Notes on the Geology of Northern California, by J. S. Diller.

34. On the relation of the Laramie Molluscan Fauna to that of the succeeding Fresh-water Eocene, and other groups, by Dr. C. A. White.

35. The Physical Properties of the Iron Carburets, by Carl Barus and Vincent Strouhal.

36. The subsidence of small particles of Insoluble Solid in Liquid, by Carl Barus.

STATISTICAL PAPERS.

A fourth series of publications, having special reference to the mineral resources of the United States, has been undertaken.

Of that series the following have been published, viz:

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1,016 pp. Price 60 cents.

In preparation:

Mineral Resources of the United States for calendar year 1885, by Albert Williams, jr.

Correspondence relating to the publications of the Survey, and all remittances, which must be by POSTAL NOTE OR MONEY ORDER (not stamps), should be addressed

TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

WASHINGTON, D. C., *May* 1, 1886.

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No. 27

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UNITED STATES GEOLOGICAL SURVEY.
J. W. POWELL, DIRECTOR

REPORT OF WORK DONE

IN THE

DIVISION OF CHEMISTRY AND PHYSICS

MAINLY DURING THE

FISCAL YEAR 1884-'85

WASHINGTON
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1886

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PREFACE.

The present bulletin contains some of the more important results obtained in the chemical laboratory of the United States Geological Survey during the fiscal year 1884–'85. It also contains two physical papers representing work which was mainly done during previous fiscal years, but completed during the one for which this bulletin is issued. These papers are practically continuations of or supplements to Bulletin 14, and bear the names of C. Barus and V. Strouhal as joint authors. It will be remembered that Professor Strouhal was officially connected with the Survey under the administration of Mr. Clarence King, and the results here given were obtained by the authors partly before and partly since his resignation.

In addition to the work herein presented a considerable amount of material has accumulated in both our chemical and our physical laboratories, representing investigations which are still in progress, but which are not yet far enough advanced to warrant publication. For example, Dr. T. M. Chatard is engaged upon an investigation concerning the genesis of the North Carolina corundums; Dr. Gooch is examining a large series of geyser products from the Yellowstone Park; Dr. Barus has in hand some researches upon the measurement of high temperatures; Dr. William Hallock is studying the effect of pressure upon rock-forming material; and I am myself at work upon problems relating to the chemical constitution of the natural silicates. All of these investigations are being pushed as rapidly as possible, and the results will duly appear in future publications.

F. W. CLARKE,
Chief Chemist.

WORK DONE IN THE DIVISION OF CHEMISTRY AND PHYSICS IN 1884-'85.

TOPAZ FROM STONEHAM, MAINE.

By F. W. CLARKE.

In August, 1882, G. F. Kunz received from N. H. Perry, of South Paris, Me., some crystals which he immediately recognized as topaz. The locality from which they came was Harndon Hill, in the town of Stoneham, Oxford County, and subsequent explorations by Mr. Kunz and Mr. Perry brought to light much interesting material.[1] Later, the place became famous as a source of the very rare species herderite; and, in addition to this mineral and topaz, the locality has yielded specimens of albite (var. cleavelandite), apatite, autunite, biotite, beryl, columbite, damourite, fluorite, gahnite, garnet, muscovite, orthoclase, quartz, triplite, and zircon, together with other material of an obscure or doubtful character.

In the latter part of 1883, Mr. C. M. Bradbury[2] published an analysis of the Stoneham topaz, which, if correct, would show the mineral to be quite unlike any topaz hitherto known. His results were as follows, and make the proportion of fluorine half as high again as the generally accepted formula for topaz would require. The figures in parentheses are added to facilitate comparison with our own data:

Sp. Gr. 3.54.

Al	27.14	(Al_2O_3, 51.26)
Si	14.64	(SiO_2, 21.37)
F	29.21	
O	28.56	
	99.55	

The peculiar interest attaching to these figures made a new analysis desirable; and accordingly the task was undertaken in this laboratory.

---

[1] See paper by G. F. Kunz, in Proceedings of the American Association for the Advancement of Science, Vol. XXXII, 1883, p. 271.

[2] Chemical News, XLVIII, 109.

Meanwhile Mr. Perry had called our attention to some apparently altered topaz, the crystals of which, having the unchanged mineral at the center, were transformed upon the surface to a dark-purple soft substance, easily cut with a knife. Between the purple zone and the topaz was a greenish, intermediate layer, which shaded off imperceptibly into the original nucleus.

Intimately associated with the topaz, in all the specimens received by us, was a mineral identified by Dr. T. M. Chatard as damourite. This mineral occurs at the locality in two forms: first, as a broadly foliated mica, much like a pale-green muscovite, and sometimes very well crystallized; and, secondly, as a massive, subfibrous, dark-green variety, suggestive of steatite or serpentine. Both forms were analyzed by Dr. Chatard, and the analyses have already been published.[1] They are reproduced here for comparison in series with those of the topaz and its alterations. The latter were analyzed by Mr. Edward Whitfield, who examined the topaz itself, the greenish intermediate layer, and the outermost purple product. The topaz was white, massive, and somewhat milky, and the method of analysis was, as in the case of Bradbury's work, the old zinc-oxide process of Berzelius. The alkalies were estimated with the aid of the bismuth-oxide method of decomposition, as proposed by Hempel and modified in this laboratory by Chatard.[1] The results may be tabulated as follows:

	A—unaltered topaz.		*B*—greenish layer.		*C*—purple zone.		*D*—massive damourite.	*E*—foliated damourite.
Sp. Gr.	3.51		3.42		2.82		....	....
Hardness	8.		7.		3.		....	....
SiO_2	31.92	......	35.15	......	44.52	......	45.19	45.34
Al_2O_3	57.38	......	53.18	......	46.19	......	33.32	33.96
F	16.99	17.21	12.88	......	0.40	0.38	....	....
H_2O	0.20	0.20	0.90	0.90	3.74	3.99	4.48	4.78
K_2O	0.15	0.12	1.52	......	2.30	......	11.06	10.73
Na_2O	1.33	1.18	1.28	......	2.82	......	1.57	1.49
FeO	......	......	......	......	......	......	4.25	3.96
MnO	......	......	......	......	0.21	......	0.58	0.51
CaO	......	......	1.32	1.42	0.30	0.48	trace.	0.22
MgO	......	......	0.17	0.14	0.14	......	0.36	0.10
	107.97		106.40		100.62		100.81	101.09
Deduct oxygen	7.16		5.42		.16			
	100.81		100.98		100.46			

If we now consider these analyses in their order, we find first that the topaz itself is ordinary topaz, having none of the anomalous character indicated by Mr. Bradbury's work. The small quantities of alkalies present may be attributed either to admixed impurity or to an incipient alteration such as is suggested by analyses B and C. The latter point clearly to a progressive change from topaz towards damourite, the fluorine and some alumina having been gradually eliminated and replaced by other constituents. This change was probably brought about by the action of potash solutions, produced by the kaolinization of adjacent feldspathic material, the removal of fluorine and alumina having been followed by the taking up of potassium. One preliminary experiment bearing upon this mode of alteration has been tried. A weighed quantity of the topaz, in fine powder, from the sample which was analyzed by Mr. Whitfield, was digested on the water bath for seven days with a weak solution of potassium carbonate. Then, after filtering, the amount of fluorine in the filtrate was estimated, and found to be 0.38 per cent. of the weight of topaz taken. That is, fluorine can be slowly extracted from topaz by the suggested process, although further experiments are needed to make the case anything like complete.

---

[1] Bulletin No. 9, United States Geological Survey.

In order to more completely prove the transformation of topaz into damourite, microscopic slides were made and examined by Mr. J. S. Diller,[1] who studied the specimen which showed the alterations most perfectly. In this specimen the purple zone had a thickness of about one centimeter and exhibited on its surface the crystalline faces of topaz. On other altered specimens even the topaz striæ were clearly visible. By means of the well-marked basal cleavage it was easy to prepare sections parallel and sections perpendicular to the vertical axis, and both sections extended from the outside of the purple border into the fresh topaz. The results of Mr. Diller's observations may be summarized as follows:

> In the topaz there are many liquid inclusions, from which the bubble readily disappears upon heating; and these are usually arranged in planes extending in nearly the same direction as and approximately parallel to the most common prismatic planes I and i-$\breve{2}$. Almost at right angles to these are numerous fissures, which lie for the most part near the same prismatic planes. Some of these fissures are filled with a finely-foliated, micaceous mineral, whose physical and optical properties, as far as they can be observed, agree fully with those of the damourite which was subjected to analysis by Dr. Chatard. The foliæ of damourite occur in fissures only, and, although considerably interwoven, they are for the most part nearly parallel to the fissures in which they lie. In the section parallel to the vertical axis of the topaz the basal cleavage was plainly seen, and nearly parallel with the latter there were prominent cross fractures.
>
> The damourite extends far into the topaz along these basal fractures in the form of veins, and from the latter it sends off tongues into the prismatic fissures. These gradually increase in size, until the topaz entirely disappears, and the whole mass is made up of scales of damourite. The position of each scale bears no definite relation whatever to the crystallographic axes of the topaz; although the foliæ are generally parallel, they are often irregularly interwoven. The fact that between the mass of the topaz and the damourite there is an intermediate zone in which both are intermingled is exceedingly important. Furthermore, the damourite always occurs in fractures belonging to the topaz, indicating clearly that the fractures were formed before the damourite and determined its position. The basal fissures of the topaz, which depend upon its basal cleavage, once extended directly through the place now occupied by damourite, showing that the same space was once filled by topaz and that the former must be an alteration product of the latter.

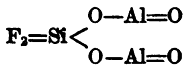
---

[1] See paper by Clarke and Diller; American Journal of Science, May, 1885.

It will at once be seen that the crystallographic and microscopic evidence is even more emphatic than the chemical analyses in pointing to the conclusion that the altered topaz is essentially damourite. And yet, if we compare the analysis of the purple material with the typical damourite examined by Chatard, we find that the transformation is chemically not quite perfect. More alumina must be lost and more potassium must be gained before the alteration can be considered completely damouritic; or, in other words, certain stages of the chemical process, although easily to be understood, are yet to be actually observed on specimens. The state of the case, as it stands in the actual specimens under consideration, is probably as follows: Analysis A represents practically unaltered topaz; B, a mixture of topaz, damourite, and an intermediate alteration product; C, a similar mixture, with the topaz almost wholly removed and the damourite overwhelmingly predominating. The intermediate product, which is perhaps microscopically identical with topaz itself, should be simply the latter species with its fluorine replaced either by oxygen, by hydroxyl, or by both; and its formation is probably a necessary antecedent to the production of the damourite. The loss of fluorine appears to have preceded the taking up of alkalies.

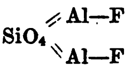
In order to make clear the relations between topaz and damourite, we may profitably consider a few structural formulæ. Reduced to its simplest empirical expression, the composition of typical topaz corresponds to the formula $Al_2 F_2 SiO_4$. This may be written structurally in seven different ways, three being as follows, and the others variations of these:

1.



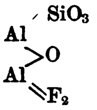
$$F_2{=}Si\Big<\begin{array}{l}O{-}Al{=}O\\O{-}Al{=}O\end{array}$$

2.



$$SiO_4\begin{array}{l}{/\!\!/}\,Al{-}F\\ {\backslash\!\!\backslash}\,Al{-}F\end{array}$$

3.

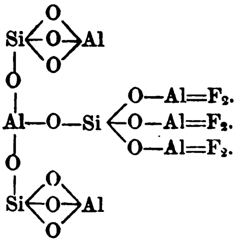


$$\begin{array}{l}\quad\;\, / \,SiO_3\\Al\\ \quad\;\, >O\\Al\\ \quad\;\, {\backslash\!\!\backslash}\,F_2\end{array}$$

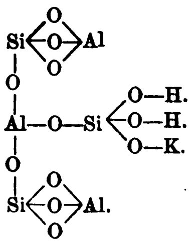
The first formula is rather improbable, the second represents an orthosilicate, the third falls under a metasilicate type. Which one is best supported by evidence?

A prime difficulty in the way of discussing the chemical structure of minerals arises from the fact that we have as yet no trustworthy means of ascertaining their true molecular weights. The formula of topaz, for example, may either be the simple expression given above or a multiple of that; and our only method of even approximately solving the problem is to study the reactions of topaz, or, in other words, its modes of alteration. Now, the simplest formula for pure damourite, and one which is commonly recognized, is $Al_3KH_2(SiO_4)_3$. That is, damourite is far more readily and probably figured as an orthosilicate than in any other way; and this fact tends to sustain the orthosilicate formula for topaz.

Inasmuch as the formula of damourite contains three SiO_4 groups, we may now triple the formula hitherto assigned to topaz, and write out in probable structural fashion the two formulæ side by side, thus—

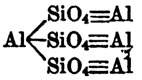


Topaz.



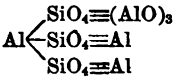
Damourite.

These results are suggestive even as they stand; but they become vastly more so if we consider with them a number of other mineral species, especially xenolite, fibrolite, paragonite, and eucryptite. Xenolite, it will be remembered, is optically almost identical with fibrolite; fibrolite is unquestionably related to topaz; paragonite is the sodium analogue of damourite, and eucryptite is notable for its easy alterability into mica. Tripling the formulæ commonly assigned to fibrolite and eucryptite and using a somewhat more condensed graphical notation, the series may be represented as follows:



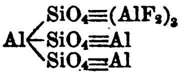
$$\mathrm{Al}{<}\begin{array}{l}\mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{array}$$

Xenolite.



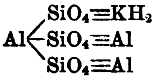
$$\mathrm{Al}{<}\begin{array}{l}\mathrm{SiO_4{\equiv}(AlO)_3}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{array}$$

Fibrolite.



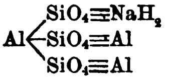
$$\mathrm{Al}{<}\begin{array}{l}\mathrm{SiO_4{\equiv}(AlF_2)_3}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{array}$$

Topaz.



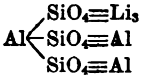
$$\mathrm{Al}{<}\begin{array}{l}\mathrm{SiO_4{\equiv}KH_2}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{array}$$

Damourite.



$$\mathrm{Al}{<}\begin{array}{l}\mathrm{SiO_4{\equiv}NaH_2}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{array}$$

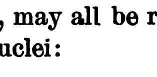
Paragonite.



$$\mathrm{Al}{<}\begin{array}{l}\mathrm{SiO_4{\equiv}Li_3}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{array}$$

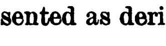
Eucryptite.

Xenolite, it will be observed, is the normal orthosilicate of aluminum; and from its formula, by simple substitution, the other formulæ are developed. This fact at once suggests the generalization that all or nearly all orthosilicates containing aluminum may be structurally regarded as substitution derivatives of the normal salt, a view which appears to be justified by many facts, and which I am endeavoring to work out in detail. A full discussion of the subject is reserved for the future, but for present purposes a few illustrations may be given. For instance, the orthosilicate micas, notably the typical muscovites, biotites, and phlogopites, may all be represented as derivatives of the following unsaturated nuclei:



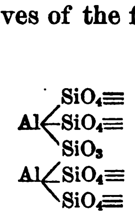
$$\mathrm{Al}{<}\begin{array}{l}\mathrm{SiO_4{\equiv}}\\ \mathrm{SiO_4{\equiv}Al.}\\ \mathrm{SiO_4{\equiv}Al.}\end{array}$$

Muscovite nucleus.



$$\mathrm{Al}{<}\begin{array}{l}\mathrm{SiO_4{\equiv}}\\ \mathrm{SiO_4{\equiv}}\\ \mathrm{SiO_4{\equiv}Al.}\end{array}$$

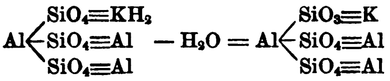
Biotite nucleus.



$$\begin{array}{l}\mathrm{Al}{<}\begin{array}{l}\mathrm{SiO_4{\equiv}}\\ \mathrm{SiO_4{\equiv}}\\ \mathrm{SiO_3}\end{array}\\ \mathrm{Al}{<}\begin{array}{l}\mathrm{SiO_4{\equiv}}\\ \mathrm{SiO_4{\equiv}}\end{array}\end{array}$$

Phlogopite nucleus.

The first of these three we find in damourite; the second, saturated with two atoms of ferrous iron, one atom of hydrogen, and one atom of potassium, fairly represents Lewis's siderophyllite; the third, satisfied by two MgF groups, three magnesium atoms, and one atom each of potassium and hydrogen, gives a typical phlogopite. If the second nucleus were to be satisfied by three calcium atoms, we should have represented the composition of a lime-alumina garnet, a formula which becomes very suggestive when we remember that garnet sometimes alters into biotite. Between these formulæ and those of the metasilicate micas are many intermediate steps; as, for example, when we dehydrate damourite, thus —

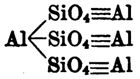


$$\mathrm{Al}\begin{cases}\mathrm{SiO_4{\equiv}KH_2}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{cases} - \mathrm{H_2O} = \mathrm{Al}\begin{cases}\mathrm{SiO_3{\equiv}K}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{cases}$$

As the lepidolite group of micas is now under investigation in this laboratory, the further discussion of mica formulæ is postponed.

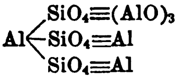
Two other series of formulæ bearing upon this system of representation are as follows:

1.



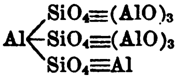
$$\mathrm{Al}\begin{cases}\mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{cases}$$

Xenolite.



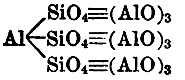
$$\mathrm{Al}\begin{cases}\mathrm{SiO_4{\equiv}(AlO)_3}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{cases}$$

Fibrolite.



$$\mathrm{Al}\begin{cases}\mathrm{SiO_4{\equiv}(AlO)_3}\\ \mathrm{SiO_4{\equiv}(AlO)_3}\\ \mathrm{SiO_4{\equiv}Al}\end{cases}$$

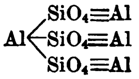
Dumortierite.



$$\mathrm{Al}\begin{cases}\mathrm{SiO_4{\equiv}(AlO)_3}\\ \mathrm{SiO_4{\equiv}(AlO)_3}\\ \mathrm{SiO_4{\equiv}(AlO)_3}\end{cases}$$

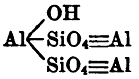
Unknown.

2.



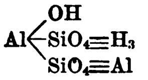
$$\mathrm{Al}\begin{cases}\mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{cases}$$

Xenolite.



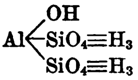
$$\mathrm{Al}\begin{cases}\mathrm{OH}\\ \mathrm{SiO_4{\equiv}Al}\\ \mathrm{SiO_4{\equiv}Al}\end{cases}$$

Westanite.



$$\mathrm{Al}\begin{cases}\mathrm{OH}\\ \mathrm{SiO_4{\equiv}H_3}\\ \mathrm{SiO_4{\equiv}Al}\end{cases}$$

Kaolin.



$$\mathrm{Al}\begin{cases}\mathrm{OH}\\ \mathrm{SiO_4{\equiv}H_3}\\ \mathrm{SiO_4{\equiv}H_3}\end{cases}$$

Montmorillonite.

The suggestiveness of such formulæ can hardly be questioned, and a close examination of them will show that they also fulfill the main purpose of structural formulæ; namely, that they indicate probable lines for fruitful synthetic research.

One more question may be included within the scope of the present paper. What has become of the fluorine withdrawn from the topaz during the process of alteration? The answer is probably not far to seek. Leached out from the topaz in the form of alkaline fluorides, it entered into new modes of union, and these are represented at the locality by the species fluorite, herderite, and apatite. The last-named mineral occurs in small crystals, and also in large dark-green masses. As an analysis of the massive apatite was made by Mr. Whitfield, I subjoin it, as a further contribution to our knowledge of the locality. The specific gravity was 3.27 and the mineral became colorless on heating.

CaO	47.60
MgO	6.08
FeO	1.44
P_2O_5	40.36
Cl	.29
F	6.84
H_2O	.11
	102.72
Deduct oxygen	2.94
	99.78

The high proportion of fluorine found in this analysis was undoubtedly due to intermixed fluorite. The large amount of magnesia, moreover, suggests the desirability of a careful search at the locality for wagnerite.

ON THE SEPARATION OF TITANIUM AND ALUMINUM, WITH A NOTE ON THE SEPARATION OF TITANIUM AND IRON.

By F. A. Gooch.

In attempting to separate titanium and aluminum it is usual to resort to that method which depends upon the action of the slightly acid solution of the sulphates when submitted to prolonged boiling. The faultiness of this method, however, becomes apparent when solutions of aluminum and titanium are compared as to behavior under the conditions. To secure the complete precipitation of titanium the excess of sulphuric acid must be kept small, while to prevent the deposition of alumina the acid must be more than enough to dissolve the same amount freshly precipitated as hydrate, in the cold. Thus, upon boiling solutions containing the equivalent of .06 grm. of titanic oxide, 2.5 grm. of free sulphuric acid, beside alkaline sulphates, in 800 cm.^{3} of water, it was found that at the end of an hour .003 grm. of titanic oxide in one case and .006 grm. in another experiment had escaped precipitation; but that, when the solution of titanium had first been precipitated by ammonia and then made just acid by sulphuric acid, every trace of dissolved titanium was thrown out on boiling. The experiment, on the other hand, of boiling a gramme of alum—roughly speaking 0.1 grm. of alumina—in 800 cm.^{3} of water shows almost immediately the deposition of some alumina, and the same thing happens when the alumina is first precipitated by ammonia and then dissolved by just enough sulphuric acid to effect the solution. The difficulty of so adjusting the acidity of the solution that no alumina shall be deposited and no titanium held up is obvious. Test paper is of no aid in the case, since the reaction of alum itself and aluminic sulphate is acid. Under the circumstances it is hardly surprising that Knop[1] should revert from the troublesome, and only under remote conditions more exact, method of separation by boiling to the convenient but indubitably inaccurate process of parting by the use of sodic hydrate. Knop employs both the dry and the wet method—the fusion of the oxides in sodic hydrate and the treatment of the salts in solution with sodic hydrate in excess; but both had long before been generally discarded, and the single experiment of acidulating the alkaline filtrate from a precipitate obtained by the treatment of a pure titanium salt according to either mode, and then making alkaline with ammonia, is enough to prove their worthlessness.

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[1] Jahrb. f. Min. 1876, p. 756; Zeit. f. Kryst. u. Min., I. 58.

In an endeavor to secure a better means of separating titanium from aluminum I have followed two lines of experimentation—the one based upon the observation that, under properly-controlled conditions, titanium is completely precipitated and alumina held in solution when an alkaline orthophosphate, strongly acidified with formic acid, is added to the solution of salts of these elements; the other, upon the solubility of alumina and the insolubility of titanic hydrate in sufficiently strong boiling solutions of acetic acid. Two preparations of titanium were used as test material in the course of the work—the solution of the fusion in sodic bisulphate of the hydrate precipitated by ammonia from the fluoride of titanium and potassium itself made from rutile and carefully purified by recrystallization; and the solution obtained by treating the carefully-prepared double fluoride with sulphuric acid, evaporating to dryness, redissolving in sulphuric acid, and diluting with water. The second mode of preparation is the better, because the amount of alkaline sulphate present in the test solution is much smaller. At first, the strength of the solution was fixed by precipitating weighed amounts by ammonia, carefully washing, igniting, and weighing the precipitate; but in the course of the work it became plain that the precipitation by means of ammonic acetate, or by ammonia with the subsequent addition of acetic acid in distinct excess, yielded more precise results. On this account, therefore, the determinations of the standard of the solutions employed in the later work were made by the acetic acid process, and the determinations by ammonia were corrected to correspond. In some of the experiments bearing upon this point, the results of which are given in the figures below, precipitations by ammonia were made in the cold and the liquid then heated to boiling; in those in which acetic acid was used just in excess, this reagent succeeded the ammonia at once, and the boiling followed; when precipitation was effected in presence of large amounts of acetic or formic acid, the acid was added in the amount intended, sodic acetate in quantity more than that necessary to decompose the sulphates present was introduced, and the clear solution heated to boiling, and kept boiling for a minute or two. The acetic acid employed was the C. P. article of commerce, and contained thirty-five per cent. of absolute acid. The amounts of it used—20%, 30%, 40%, 50% by volume—correspond to 7%, 10.5%, 14%, 17.5% of absolute acid. The formic acid contained twenty-seven per cent. of pure acid, and when it is said that there was in solution 5.4% of it, the absolute acid is meant; but it was the weaker acid, to the amount of 20% of the entire volume, which was actually used. The experiments were made in sets, and so appear in the record, in consequence of changes (due to slight depositions from time to time) in the strength of the test solution, which necessitated redeterminations of standard.

	Weight of solution.	TiO_2 found.	TiO_2 in 50 grm.	Mode of precipitation.
(1)	52.7370 grm.	0.3177 grm.	0.3012 grm.	By ammonia.
(2)	52.7610 “	0.3180 “	0.3012 “	
(3)	52.7620 “	0.3076 “	0.2912 “	By ammonia and excess of acetic acid.
(4)	41.8010 “	0.2436 “	0.2914 “	
(5)	52.9420 “	0.3381 “	0.3193 “	By ammonia.
(6)	53.0200 “	0.3384 “	0.3191 “	
(7)	10.6300 “	0.0667 “	0.3137 “	By acetic acid 7% by volume.
(8)	10.6960 “	0.0671 “	0.3137 “	
(9)	21.1030 “	0.1285 “	0.3044 “	By ammonia.
(10)	21.1480 “	0.1290 “	0.3049 “	
(11)	21.0810 “	0.1248 “	0.2960 “	By acetic acid 14% by volume.
(12)	21.1670 “	0.1259 “	0.2974 “	
(13)	21.0620 “	0.1270 “	0.3015 “	By ammonia.
(14)	21.2310 “	0.1279 “	0.3012 “	
(15)	10.4370 “	0.0617 “	0.2956 “	By acetic acid 10.5% by volume.
(16)	10.6590 “	0.0629 “	0.2950 “	
(17)	10.4870 “	0.0618 “	0.2946 “	By acetic acid 14% by volume.
(18)	10.8820 “	0.0637 “	0.2940 “	
(19)	10.4700 “	0.0615 “	0.2938 “	By formic acid 5.4% by volume.
(20)	10.7410 “	0.0627 “	0.2919 “	
(21)	52.3960 “	0.3396 “	0.3230 “	By ammonia.
(22)	52.4140 “	0.3378 “	0.3222 “	
(23)	52.6350 “	0.3340 “	0.3262 “	
(24)	52.5600 “	0.3372 “	0.3208 “	By acetic acid in distinct excess.
(25)	52.4830 “	0.3366 I “ 0.3363 II “	0.3207 “ 0.3204 “	
(26)	52.3700 “	0.3348 “	0.3196 “	By acetic acid 17.5% by volume.
(27)	52.6420 “	0.3374 “	0.3205 “	

It will be noticed in the examination of these figures that parallel determinations usually agree very closely. The amounts of titanic oxide indicated by those experiments in which the precipitation was made by ammonia are much in excess of those in which acetic acid was added subsequently. Thus the difference between (1), (2) and (3), (4) amounts to more than three per cent. of the total amount of the former; that between (5), (6) and (7), (8), to a little less than two per cent.; that between (9), (10) and (11), (12), to about two and a half per cent.; and a correction of more than two per cent. must be applied to (13), (14) to bring them to correspondence with (15), (16), (17), (18). The difference between (21), (22), (23) and (24), (25), (26), (27) is about one per cent., and the smallness of this figure in comparison with the differences previously noted is apparently explicable by the fact that the solution of titanium employed in the last determinations was prepared by the second of the methods mentioned above and carries a smaller amount of alkaline sulphate. The tendency of titanic hydrate to include the sulphates of the alkalies is not strange in view of the well known conduct of aluminic hydrate under similar circumstances, but the amount thus held is rather surprising. The experiments in which different proportions of free acid were introduced go to show, very strikingly, that, if acetic acid exerts any solvent action whatever upon the precipitate thrown down by boiling the acetate, that action is very slight. Thus, between the mean of (24), (25) and that of (26), (27,)—the one set precipitated by ammonia and treated before boiling with just a distinct excess of acetic acid, the other pair thrown out of a large volume, 700 cm.^{3}, one-half of which was acid of 35% strength, by boiling—we find a difference of but 0.0007 grm., and between the mean of (15), (16) and that of (17), (18), the difference (magnified five times by reference to 50 grm. portions) is 0.0010 grm. In (25), too, we have an experiment in which the weighed precipitate was fused in sodic carbonate, dissolved, and again precipitated as before and weighed, the two weights differing by 0.0003 grm. Moreover, the filtrates from the precipitates thrown out in presence of an excess of acetic acid, when neutralized with ammonia, failed invariably to show the smallest precipitate, and in direct experiments upon the sensitiveness of the reaction it was found that on the addition of 0.0005 grm. of titanic oxide in solution to 100 cm.^{3} of 35% acetic acid carrying a little sodic acetate a distinct precipitate appeared almost immediately on boiling. It is plain, therefore, that so far as concerns the purpose in hand the insolubility of the titanium precipitate in acetic acid may be taken as absolute. The small apparent losses to be observed in some of the determinations in which a large excess of acetic or formic acid was employed are probably explicable by the tendency of the precipitate to change its consistency as the amount of free acid increases, and, in very acid solutions, to show an inclination to adhere in small amounts, but quite persistently, to the vessel in which precipitation takes place. The adherent precipitate may be dislodged with ease by putting a little hydrochloric acid into the beaker to which the precipitate adheres, covering and heating gently so that the acid volatilized may condense upon the walls of the beaker and again run down. By then rubbing the walls of the beaker a little and adding ammonia in excess, the trace of residual titanium is completely recovered. This method of recovery was applied in (26), (27).

In preliminary experiments upon the first of the methods which seemed to promise a separation of titanium and aluminum, it was found that the precipitation of titanium by an alkaline orthophosphate is complete in the presence of a large amount of acetic or formic acid, and that, in the cold, and under conditions otherwise properly controlled, aluminic phosphate fails to appear. To hold up the alumina by means of acetic acid requires some care in the adjustment of the acid and phosphate, and to redissolve the precipitate once formed is a matter of considerable difficulty. Thus, to clear the solution of a precipitate produced by 1.5 grm. of the phosphate of soda and ammonia upon 0.1 grm. of alumina, it was necessary to dilute the liquid to a volume of 250 cm.^{3} and add acetic acid until there was in the solution at least five per cent. of absolute acid; and the addition of 1.5 grm. more of the precipitant again precipitated aluminic phosphate. Formic acid, however, is more active, and the balance between it and the precipitant not so delicate. When the proportion of three parts by weight of absolute formic acid to two parts of microcosmic salt is kept, the aluminic phosphate does not fall; and if, because of a deficiency of acid, precipitation does take place, the liquid immediately clears as soon as the proportion of acid and precipitant is restored. Formic acid, therefore, was used in the experiments about to be described. The test solution of titanium was that employed in the previous experiments (1) to (20), but, inasmuch as the error of the process had not yet been remarked, the standards were determined by precipitating by ammonia, and are therefore to be corrected. The application of a correction of two and one-half per cent. to the apparent weights of titanic oxide found by the ammonia process—the mean correction for (1), (2), (5), (6), (9), (10), (13), (14)—cannot lead far away from the truth, since the difference between the maximum and minimum corrections observed amounts for the quantity of material employed in these experiments to but 0.0002 grm. Determinations of standard, original and corrected, are given in (28), (29), (30), and (31).

	Weight of solution.	TiO_2 found.	Corrected TiO_2 in 50 grm.	Corrected TiO_2 in 50 cm.^{3}
(28)	52.7660 grm.	0.3867 grm.	0.3572 grm.	0.3771 grm.
(29)	52.8410 "	0.3869 "	0.3569 "	
(30)	52.5380 "	0.3810 "	0.3627 "	
(31)	52.6920 "	0.3822 "	0.3627 "	

A portion of the solution, the standard of which is set by (28) and (29), was diluted to ten times its volume, and 50 cm.^{3} of the diluted solution were used in each of the experiments immediately following. These were made to determine whether the precipitate was definite in composition and might be weighed as such. Precipitation was effected by a solution of microcosmic salt acidified with formic acid. The precipitates of (32) and (33) were collected on paper, that of (34) on asbestus, and all were ignited and weighed directly.

	Amount taken.	TiO_2 and P_2O_5 found.	TiO_2 by standard.	P_2O_5 by difference.
(32)	50 cm.^{3}	0.0731 grm.	0.0377 grm.	0.0354 grm.
(33)	"	0.0640 "	0.0377 "	0.0263 "
(34)	"	0.0753 "	0.0377 "	0.0376 "

The phosphate obtained by Merz[1] by precipitating in presence of hydrochloric acid containing two molecules of TiO_2 to one of P_2O_5 requires 0.0326 grm. of P_2O_5 to 0.0377 grm. of TiO_2. It will be noticed that in two determinations the P_2O_5 is in considerable excess of the amount demanded by this proportion, and in one, in deficiency. The idea of weighing the phosphoric anhydride and titanic oxide together was therefore abandoned.

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[1] Jour. prakt. Chem., XCIX, 157.

In experiments (35), (36), (37), the titanium was present alone; in (38), (39), 2 grms. of alum were added to the solution before precipitating by means of the mixture of microcosmic salt and formic acid, 5 grm. of the former being employed to 8 grm. of the latter. The precipitates of all, excepting (35), were carefully washed, ignited, fused with sodic carbonate, and the product of fusion was dissolved in water, the insoluble titanate separated from the soluble phosphate by filtration and washing, ignited, again fused with a little sodic carbonate, the result of fusion dissolved in strong sulphuric acid, diluted with water, and precipitated by ammonia with the subsequent addition of acetic acid, and boiling. Experiment (35) was conducted in like manner, excepting that the sodic titanate was dissolved off the filter by means of a mixture of hydrochloric and oxalic acids, the latter destroyed by potassic permanganate (since there is danger that in presence of ammonic oxalate the titanium may not be completely precipitated by ammonia), ammonia added in excess, then acetic acid to strongly acid reaction, and the liquid boiled. This mode of treating the acid titanate is not desirable, since the titanic hydrate, if precipitated but once subsequently, retains a trace of manganese. To fuse the titanate with sodic carbonate, and then treat the melt with strong sulphuric acid, is probably the best way of getting the titanium into solution again. The test solution of (28) and (29) was employed in experiment (35) and that of (30) and (31) in the rest.

From experiments (36) and (37), together with (35), which, as has been remarked, would naturally give figures slightly too high, it appears that the method indicates with accuracy the amount of titanium present. Experiments (38) and (39) indicate that the separation from alumina is not unreasonably inexact.

	Weight of solution.	TiO_2 found.	TiO_2 by standard.	Error.	
(35)	5.2220 grm.	0.0383 grm.	0.0373 grm.	0.0010 grm.	+
(36)	5.2300 "	0.0371 "	0.0370 "	0.0001 "	+
(37)	5.3840 "	0.0380 "	0.0381 "	0.0001 "	—
(38)	5.2920 "	0.0367 "	0.0374 "	0.0007 "	—
(39)	5.2540 "	0.0383 "	0.0372 "	0.0011 "	+

The tediousness of filtration, which is a consequence of the nature of the phosphate precipitate, is the great objection to the method, and on account of it the testing was pushed no further, attention being turned instead to the second line of experimentation.

The incompleteness of the precipitation of alumina by the basic acetate process in presence of a large excess of acetic acid, suggested the attempt to hold up alumina entirely by means of a sufficient excess of acetic acid while precipitating titanium. Experiments to determine the amount of acetic acid necessary to prevent the precipitation of alumina from a boiling solution of the acetate, indicate that amounts of absolute acid in excess of five per cent. by volume of the solution are adequate to the purpose, and that the addition of sodic acetate in reasonable amounts does not sensibly affect conditions. It appears, further, that the addition of a very small quantity of titanium in solution to the clear boiling solution of alumina in acetic acid occasions at once a perceptible precipitation. Thus, 0.0005 grm. of titanic oxide in solution produced a distinct and appreciable opalescence in 500 cm.^{3} of liquid containing 10 grm. of alum, 15 grm. of sodic acetate (about twice the amount necessary to convert the sulphate of alumina to the acetate), and seven per cent. by volume of absolute acetic acid.

In respect to holding up alumina, formic acid acts like acetic acid, but more potently.

In the following experiments to test the method quantitatively two solutions of titanium were employed: in (40) and (41), the solution the value of which was fixed by (15) to (18); in (42) to (46), the solution whose standard was set by (24) to (27). To the cold solution of titanium containing a little free sulphuric acid, together with some alkaline sulphate, were added 5 grm. of alum (approximately 0.5 grm. of alumina), 20 grm. of sodic acetate (which was always more than enough to effect the entire conversion of the aluminic and titanic sulphates to acetates), acetic acid to such amount that in experiments (42), (43), (44) there should be in the solution seven per cent. by volume of absolute acid and in the remaining experiments ten and one-half per cent. by volume, and water to make the entire volume 250 cm.^{3} in (40) and (41) and 400 cm.^{3} in the rest. The clear solutions obtained in this manner were raised quickly to boiling, kept at that point for a minute, and removed from over the burner so that the precipitate might settle, as it does almost immediately. The supernatant liquid was decanted upon a filter sufficiently porous to permit very rapid filtration,[1] and the precipitate added immediately thereafter and washed with 7% acetic acid, followed finally by hot water. The washed precipitate was dried, ignited, and weighed. The precipitate once upon the filter and drained becomes more compact and easily washed, and strong ignition of fifteen or twenty minutes over a good Bunsen burner, after the paper is thoroughly ashed, reduces it to a weight which neither the blast-lamp nor ignition in an atmosphere of ammonic carbonate changes.

	Weight of solution.	TiO_2 found.	TiO_2 by standard.	Error.
(40)	10.4910 grm.	0.0645 grm.	0.0618 grm.	0.0027 grm. +
(41)	10.5970 "	0.0656 "	0.0624 "	0.0032 " +
(42)	20.9520 "	0.1450 "	0.1343 "	0.0107 " +
(43)	21.1750 "	0.1439 "	0.1357 "	0.0082 " +
(44)	21.0250 "	0.1431 "	0.1347 "	0.0084 " +
(45)	20.8740 "	0.1393 "	0.1338 "	0.0055 " +
(46)	21.0570 "	0.1402 "	0.1349 "	0.0053 " +

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[1] The paper No. 589 of Schleicher and Schüll is excellent for the purpose.

It is quite obvious that a single precipitation by the method used does not yield titanic oxide free from alumina. The weighed precipitate of each experiment was therefore fused with a small quantity of sodic carbonate, and the product of fusion treated in the crucible with strong sulphuric acid, which gradually with the aid of gentle heat dissolved everything completely. This solution after cooling was poured directly into 100 cm.^{3} of cold water, and, the liquid remaining clear, ammonia was added just to alkalinity, and then dilute sulphuric acid corresponding to 2.5 grm. of pure acid. The precipitate thrown down by ammonia was gradually, but after a few minutes, entirely redissolved, acetic acid was added until it amounted in terms of absolute acid to ten and one-half per cent. of the entire volume, 20 grm. of sodic acetate were introduced, the solution was boiled, and the precipitate treated as previously described. The results of this second treatment are given below.

	Weight of solution.	TiO_2 found (II).	TiO_2 by standard.	Error.
(40)	10.4910 grm.	0.0624 grm.	0.0618 grm.	0.0006 grm. +
(41)	10.5970 "	0.0623 "	0.0624 "	0.0001 " —
(42)	20.9520 "	0.1373 "	0.1343 "	0.0030 " +
(43)	21.1750 "	0.1385 "	0.1357 "	0.0028 " +
(44)	21.0250 "	0.1369 "	0.1347 "	0.0022 " +
(45)	20.8740 "	0.1357 "	0.1338 "	0.0019 " +
(46)	21.0570 "	0.1383 "	0.1349 "	0.0034 " +

In experiments (40) and (41), in which comparatively small amounts of titanium were employed, the separation from alumina was reasonably good after the second precipitation, but in (42) to (46) the larger quantities of titanic oxide still retained notable amounts of alumina. The precipitates of (45) and (46) were, therefore, treated again just as before, to determine the effect of a third precipitation.

	Weight of solution.	TiO_2 found (III).	TiO_2 by standard.	Error.
(45)	20.8740 grm.	0.1347 grm.	0.1338 grm.	0.0009 grm. +
(46)	21.0570 "	0.1360 "	0.1349 "	0.0011 " +

Three precipitations left the titanic oxide of these experiments nearly free from alumina, but three such treatments involve a good deal of labor, and, moreover, it is evident that the precipitate still holds with tenacity traces of alumina. The experiment of attempting to remove residual alumina, after a single precipitation, by treating the product of fusion of the precipitate in sodic carbonate with boiling water, filtering, igniting the residue, again fusing with a little sodic carbonate, and proceeding from this point to dissolve in sulphuric acid and precipitate once more as before, was therefore tried, and the result is given in the record of (47) to (50).

	Weight of solution.	TiO_2 found.	TiO_2 by standard.	Error.
(47)	20.8640 grm.	0.1329 grm.	0.1337 grm.	0.0008 grm.—
(48)	21.1100 "	0.1345 "	0.1354 "	0.0009 " —
(49)	20.9100 "	0.1332 "	0.1340 "	0.0008 " —
(50)	21.0020 "	0.1348 "	0.1346 "	0.0002 " +

This mode of treatment appears to remove the last traces of alumina and yields a reasonably good separation.

It appears therefore, to recapitulate, that for the separation of titanium and aluminum either of the processes set forth in the preceding work may serve. The first, however—which is, in brief, the treatment of the solution containing salts of the elements in question with a mixture of microcosmic salt and formic acid, in the proportion of two to three by weight, together with enough ammonic formate to take up the stronger acids, fusing the precipitate in sodic carbonate, extracting with water, fusing the residue in a small amount of sodic carbonate, dissolving in sulphuric acid and precipitating by ammonia with the subsequent addition of acetic acid, and boiling—though probably fairly accurate, is, on account of the nature of the precipitated phosphate, not comparable with the second method in point of convenience. The latter process, which involves many different manipulations—the introduction into the solution of titanium and aluminum of enough acetic acid to make from seven to eleven per cent. by volume of the absolute acid, together with sufficient sodic acetate to fix all of the stronger acids in sodium salts, boiling, filtering, and washing with acetic acid of 7% strength, fusing the ignited precipitate in sodic carbonate, extracting with boiling water, again fusing the residue with a little sodic carbonate, dissolving in strong sulphuric acid and pouring this solution into water, neutralizing with ammonia, redissolving the precipitate in a known amount of sulphuric acid, and precipitating finally by boiling with acetic acid and sodic acetate as at first—and appears in the description to be long and tedious, may in reality be carried out with ease and rapidity, the operations being generally short and not of a difficult nature.

In most cases in which titanium is to be separated from aluminum, it is necessary to effect the removal of iron as well. Some experiments looking to the separation of titanium and iron, by boiling the acetates in presence of a large excess of acetic acid, were unsuccessful; for, though an excess of acetic acid amounting to eleven per cent. of absolute acid in the solution is enough to prevent the deposition of a basic ferric acetate, it appears, unexpectedly, that in presence of ferric acetate in solution the titanium shows a very marked tendency to remain dissolved. Thus, an amount of iron alum the equivalent of 0.2 grm. of ferric oxide, together with 10 grm. of sodic acetate and seventeen per cent. of absolute acetic acid, in a total volume of 400 $cm.^3$, held 0.06 grm. of titanic oxide completely in solution during boiling prolonged a quarter of an hour. In an experiment the counterpart of this, excepting only the addition of sodic acetate, the titanium began to deposit at once on boiling; and Streit and Franz,[1] in proposing the ebullition of the sulphates in presence of a large excess of acetic acid as a means of procuring titanic oxide free from iron, claim a complete precipitation under these conditions. The behavior of the sulphates of titanium and zirconium when in solution together appears to be analogous to this action of the acetates of iron and titanium, and iron in the ferric condition is generally supposed to influence somewhat the precipitation of titanium from the solution of the sulphates.

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[1] Jour. prakt. Chem., CVIII, 65.

When iron and titanium appear together in solution and are to be separated, the choice lies between Stromeyer's application of Chancel's hyposulphite method,[1] which yields milky filtrates—always undesirable—and that process which involves the precipitation of iron by ammonic sulphide in presence of ammonic tartrate to hold up the hydrates which would be precipitated in its absence. This latter method has been regarded as an undesirable one, chiefly on account of the inconvenience involved in the evaporation of the filtrate from the ferrous sulphide and the ignition of the residue to remove the tartaric acid, and so to permit the recovery of the bases. The difficulty in question may be obviated, however, by destroying the tartaric acid by potassic permanganate added gradually to the hot solution containing enough free sulphuric acid to leave some excess after the conversion of all the permanganate. The oxidation of tartaric acid by potassic permanganate does not, as is well known, yield carbonic acid and water alone, but gives rise also to a considerable quantity of formic acid as an intermediate product. When the permanganate begins to act upon the formic acid, the oxidation going on more slowly, results in the deposition of a brown manganic hydrate, which, if any tartaric acid remains in solution, redissolves quite rapidly, and, in presence of formic acid as the only reducing agent, more slowly. When, therefore, manganic hydrate is abundantly precipitated in the boiling solution and does not perceptibly dissolve, it is quite certain that the conversion of the tartaric acid to formic acid—which is all that is needed in this case—has been accomplished; but for the sake of greater security the addition of permanganate may be continued until its color shows in the solution. It is well, however, to make use in this process of a known amount of tartaric acid—experience has shown that an amount equal to three times the weight of the oxides to be held in solution is sufficient, unless ammonia be used in enormous excess and the boiling prolonged—and to employ for its destruction two and a half times its own weight of potassic permanganate, this quantity being more than enough to carry the oxidation to the final products, providing there were no deposition of manganic hydrate. The manganese thus introduced into the solution may be removed by two acetate precipitations, which, if alumina is to be separated, must be made at any rate, even if no manganese be present.

To separate titanium, aluminum, and iron, therefore, I find it most convenient to precipitate the iron by passing hydric sulphide into the faintly ammoniacal solution of the oxides in ammonic tartrate, taking care that the solution is still ammoniacal just before filtering; to destroy the tartaric acid in the filtrate, after acidifying and boiling off the hydric sulphide by means of potassic permanganate in the manner just described, redissolving residual manganic hydrate by the addition of a little ammonic bisulphite and boiling off the excess of sulphurous acid; and to separate the titanium and aluminum by the acetate process.

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[1] Ann. Ch. Pharm., CXIII, 127.

A single point in the analysis of silicates may be worthy of note in this connection. If phosphoric acid be present, as is often the case, the separation of titanium from silica by the action of cold water upon the product of fusion in sodic or potassic bisulphate is liable to uncertainty, on account of the formation of the insoluble titanic phosphate which remains partly with the silica and in part clouds the filtrate. The silicious residue should, therefore, be treated with sulphuric and hydrofluoric acids to recover titanium which may be with the silica. It is better in most cases to effect the decomposition of a silicate by means of one of the fluoride methods or by fusion in an alkaline carbonate, the melt in the latter case being acidified with hydrochloric acid, and the residue after evaporation and filtration worked over with sulphuric and hydrofluoric acids for the recovery of that portion of the titanium which remains insoluble after the evaporation.

A METHOD OF FILTRATION BY MEANS OF EASILY SOLUBLE AND EASILY VOLATILE FILTERS.

By F. A. Gooch.

The processes of analysis in which it is desirable to redissolve precipitates from the filter after washing, or to separate a mixed precipitate into parts by the action of appropriate solvents, are many.

When a complete solution is the object and the precipitate yields easily to solvents which do not affect paper injuriously, the use of the ordinary filter offers no difficulty. When, however, precipitates are to be treated with reagents which disintegrate paper filters, the case is different; and the attempt to remove, by solvents, any individual part of a mixed heterogeneous mass upon a filter is always an uncertain matter. As examples of cases of this sort, difficult to deal with, we may take the solution of acid sodic titanate in strong hydrochloric acid; or, the purification of baric sulphate from included salts, by digestion in strong hydrochloric acid; or, the separation of sulphides which are soluble from those which are insoluble in alkaline sulphides; or, the washing out of free sulphur from precipitated sulphides by means of carbon disulphide; or, the separation of calcic and baric sulphates by the action of sodium hyposulphite. In cases of this nature it is often convenient to make use of the asbestus filter which I have previously described;[1] but this sometimes has its disadvantages. Thus, to recur to the examples just cited, acid sodium titanate may be filtered and washed upon an asbestus filter, and felt and precipitate may be treated together with hydrochloric acid, but it will be impossible to determine when solution is effected, because of the floating asbestus; and in separating the sulphides it would be necessary to know the weight of the asbestus felt, since it must be weighed finally with the insoluble sulphides, unless removed by a special treatment which involves the solution, filtration, and reprecipitation of the latter.

It is to meet cases like these that I have sought a filter which, in the reversal of the ordinary mode of separating filter and precipitate, should dissolve easily in solvents which do not affect the ordinary precipitates met with in analysis. The material which seems best suited to the case—light and fluffy, capable of making secure filters of any desirable degree of porosity, sufficiently insoluble in water and aqueous solutions of salts, alkalies, and acids (excepting strong sulphuric, strong nitric, and glacial acetic acids), easily soluble in naphtha, benzol, carbon disulphide, ether, boiling alcohol, and essential oils, and not too costly—is anthracene.

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[1] Proc. Amer. Acad., Vol. XIII, p. 342.

The mode of preparing and using the filter is simple. Anthracene is slightly moistened with alcohol to make it miscible with water, diluted to the right consistency, and applied to the same apparatus, and in the same way, as the emulsion of asbestus which is employed in making asbestus felts. That is to say, enough of the emulsion in water to form a layer of the proper thickness is poured into a perforated crucible which is held tightly in a packing of rubber tubing stretched over a funnel fitted in the usual manner to a vacuum flask or receiver. After washing with water the filter is ready for use. If the felt happens to be too coarse for the use of the moment, it may be made as close as need be by coating the felt first deposited with a finer emulsion, made by dissolving anthracene in hot alcohol and precipitating with water. When voluminous precipitates are to be filtered, the large perforated cone described in the former paper, to which I have referred, may be substituted with advantage for the crucible; or Cooke's improved form[1] of Carmichael's process of reverse filtration may prove most useful. In using the cone it is well to apply the anthracene in a thick layer.

To remove the anthracene filter from a precipitate, it is only necessary to act with the proper solvent. It is usually convenient to stand the crucible containing precipitate and felt in a small beaker, add enough of the solvent, and gently warm until the anthracene dissolves. On the addition of water, or the reagent to work upon the precipitate, the solution of anthracene floats, and nothing remains to obstruct or obscure the action. If the precipitate dissolves entirely, the solution of anthracene may be separated from the aqueous solution by simply pouring the fluid upon a filter previously moistened with water, when the solution in water runs through, and the anthracene and its solvent remain and may be washed indefinitely with water.

If, on the other hand, the case is one of the division of precipitates, the anthracene and its solvent may be made to pass the filter, after the water has run through, by adding a little alcohol to overcome the repulsion between the solution and the water which fills the pores of the filter, the precipitate which stays behind being washed first with a solvent of anthracene, and then, if necessary, with alcohol followed by water; or, if the vacuum filter be used (either paper or asbestus, according to the circumstances of the case), both liquids leave the precipitate and traverse the filter together.

In general, I prefer benzol as the solvent for anthracene, but some advantage may be gained in special cases by a proper choice of solvents. Thus, in removing intermixed sulphur from precipitated sulphides, both the anthracene and the sulphur may be dissolved in carbondisulphide in a single operation.

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[1] Proc. Amer. Acad., Vol. XII, p. 124.

The ready volatility of anthracene, at a temperature very near its melting point, 213° C., makes it easily separable in cases when to remove it by a solvent is not advisable. The treatment of a solution of anthracene, for example, with strong sulphuric or nitric acid, is apt to produce carbonaceous or gummy residues. In such cases it is well either to heat precipitate and filter directly, or to first remove them from the crucible by means of a solvent for anthracene, then evaporate this and raise the heat gently until the anthracene has vanished. The purification of precipitated baric sulphate, by dissolving it in hot, strong sulphuric acid, and reprecipitating by dilution, is a case in point, and one, too, in which the reversed filter may be used with great advantage. It may be remarked, in passing, that, if one does not happen to possess a platinum rose and does happen to have at disposal a perforated crucible, a very fair reversed filter may be improvised of the crucible, a piece of glass tubing, and a rubber stopper, the last being fitted to the crucible and the tube passed through nearly to the perforated bottom.

At every point in the preparation and use of the anthracene filter, I have found the manipulation peculiarly easy.

THE RELATION BETWEEN ELECTRICAL RESISTANCE AND DENSITY, WHEN VARYING WITH THE TEMPER OF STEEL.

By C. BARUS and V. STROUHAL.

EXPERIMENTAL RESULTS.

Introductory.—Throughout No. 14 of the series of Bulletins of the United States Geological Survey it was our constant endeavor to keep before the mind certain lines of electrical research, such as would immediately advance our knowledge of the influence of the mechanical condition of steel on its electrical and magnetic qualities. We pointed out, in particular, the urgency of a minute study of the change of density experienced by steel on passing from hard to soft, as well as the critical importance of the nature and variation of the internal structure of a tempered bar. We called attention to our ignorance of many essential features of the process by which hardness is imparted and of the conditions subject to which hardness is received. We attempted to supply a more rigid interpretation for the magnetic relations of linear rods and for the temper-datum of the oxide films.

To most of these points we have since been able to give more or less attention, although only the small part referring to the density and conductivity of steel is sufficiently in progress to deserve special mention here.

Tempering.—In making the present measurements we used Stubs' best steel, furnished by Mr. William Grunow, of West Point. The rods are about a foot in length, and drawn very accurately circular, a desideratum. They were tempered in a way essentially the same as that employed in all our researches. We found it expedient, however, to modify the apparatus for glass-hardening in a way enabling the experimenter to work with much greater facility and expedition, as well as to quench (chill) in baths of any desirable temperature. It will be described elsewhere. We will mention in passing that the sections of our steel rods, before and after tempering, were found to differ in marked degree; that the sense of this difference is precisely the opposite of the effect to be attributed to temper. Certain incidental gravimetric measurements, for instance, showed the following results:

TABLE 1.—*Certain gravimetric measurements of section* (q), *soft and glass-hard.*

Number.		Soft.	Hard.	
37-54	$q=$	0.001537	....	(Thin.)
30-36	$q=$	0.005231	0.005162	(Intermediate.)
55-60	$q=$	0.01268	0.01257	(Thick.)

The actual effect of temper is here a diminution of the sectional area; the anticipative effect would be an increment of about twice the amount (Cf. Table 14). This anomalous result is probably attributable to the tensile strain under which the wires are glass-hardened. It is not easily avoided.

Earlier results.—Values for the electrical resistance of steel will be found in great number in the bulletin cited, and the mean results of these we will frequently be able to utilize with advantage in the present text. Results for the density of steel when in the extreme states, hard and soft, are also available in any number and for every variety of steel. But Dr. Fromme[1] seems to have been the first and indeed the only observer who attempted to trace the change of density of steel passing *continuously* from the initial state of temper to the final state. We give his summarized results in Table 2, where ρ denotes the radius in centimeters, v the specific volume of the rods examined. For the sake of clearness in comparison, we add, moreover, the probable mean values of electrical resistance characteristic of the different states of temper under consideration. In doing this we remark that the loci thus obtained, though not strictly correct ("dispersed"), will exhibit the main features of the true diagram in about the same way in which the fundamental characteristics of the solar spectrum may be shown by a number of different prisms, no two spectra, however, being exactly alike.

TABLE 2.—*Dr. Fromme's results for specific volume* (v), *for different diameters* (2ρ), *with approximate electrical resistances* (s) *added.*

Temper.	$2\rho=0.7$ v	$2\rho=0.42$ v	$2\rho=0.265$ v	$2\rho=0.255$ v	Mean s
Commercial, soft	1.00000	1.00000	1.00000	1.00000	....
Hard	1.00772	1.01000	1.01285	1.01210	(46)
Yellow-annealed	1.00347	1.00495	1.00660	1.00620	(26)
Blue-annealed	1.00217	1.00425	1.00370	1.00205	(20)
Gray-annealed	0.99957	1.00060	1.00055	0.99930	(18)
Soft	....	1.00175	1.00215	1.00340	(16)

In endeavoring to interpret these results we encounter a serious difficulty in consequence of the absence of a sufficient number of intermediate points. But anticipating certain results below and restricting our observations for the present to the data between "*hard*" and "*gray annealed*," we find all the points lying on curves of remarkably definite character. Even closer agreement is apparent in the results for thin rods and in the results for thicker rods. Indeed, it is only necessary to shift the values for specific resistance through a small interval—an interval insufficiently large to comprehend the electrical behavior of good commercial steels for the same states—in order to obtain loci of very simple kind. We show below that, even in the case of an elementary linear relation between volume and resistance—such, for instance, as approximately holds for thermal expansions—the simple law, in case of structural heterogeneity, may lead in the aggregate to very complex results.

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[1] C. Fromme: Wied. Ann., VIII, p. 352, 1879.

Fromme's data, however, contain a remarkable and almost anomalous phenomenon, viz, expansion of volume on passing from "*gray*" to "*soft*." This implies a march through a maximum of density somewhere between these two limiting states. The peculiar behavior in question, when associated with Chwolson's[1] discovery of a minimum of resistance of steel, and our results on the maximum of magnetizability—all which phenomena occur under like circumstances of temper, approximately—lead us to attach great importance to the precise definition of this singular state.

Finally, the inferences, which in this paragraph are only touched upon, are not dependent on merely qualitative analogies. They are often strikingly substantiated by estimates obtainable from a variety of known quantitative results. It is curious that this variation, which draws into close affinity an electrical function and one of the simplest mechanical functions of the physical state of steel, has not hitherto been made the subject of more searching investigation. If, as we surmise, the electrical manifestations of hardness may be regarded independent of any chemical change which steel during tempering undergoes, it would seem that the relation between volume and resistance is at once raised to higher and more general importance than that of being a mere peculiarity of steel.

Difficulties of measurement.—An accurate measurement of the simultaneous variations of resistance and density is experimentally difficult. The change of density due to the tempering of steel lies well within 2 per cent. To measure this small increment with an accuracy of 1 per cent. necessitates a measurement of the total density to within 0.02 per cent. This is readily feasible, provided the given sample is sufficiently large and of convenient shape. From such a piece,[2] however, it would be impossible to measure the electrical quality with any serviceable degree of accuracy whatever. For resistance measurement it is necessary to have the material in wire form,[3] *i. e.*, to give it precisely the shape least adapted for desirably accurate density measurements. Reasons of this kind at first induced us to doubt the satisfactory feasibility of the present series of correlative measurements. The results show that the determinations can well be made.

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[1] Chwolson: Mél. Phys. de St. Pétersbourg, X, p. 379, 1877.

[2] Kirchhoff's and other methods require special apparatus.

[3] In the proposed magnetic experiments the use of linear rods is essential; moreover, such alone can be hardened homogeneously.

Measurement of density.—In our early experiments we used a direct method for density measurement, employing a balance counterpoise with a lateral arm so adjusted as to swing the long (30 cm.) thin wire from a silk fiber in a stand-glass of water. But the results obtained were not reliable within 0.1 per cent. The pycnometer, therefore, is the only apparatus available for the present purposes. The mean constants of the flasks and of the capillary stems of the pycnometers used follow:

TABLE 3.—*Mean constants of the pycnometers.*

	No. 2.	No. 3.	No. 4.
Total weight ....grm..	5.43	5.67	5.47
Total capacity, H_2O ....grm..	3.51	3.39	3.64
Flask (cylindrical):			
Height ....cm..	3	3	3
Diameter, external ....cm..	1.3	1.3	1.3
Capillary stem:			
Internal diameter of the tube ....cm..	0.030	0.032	0.030
Mass H_2O, per cm ....grm..	0.00070	0.00079	0.00070
Temperature H_2O, per cm., at 25°	0°.80	0°.93	0°.77

The hard wires were so broken and were used in such quantity as almost wholly to fill the flask. Having filled it with water at room temperature, we allowed it to stand in the balance-case until the position of the meniscus became fixed. The weight was now taken and the operation repeated after the lapse of one hour or more. The temperature could then be regarded as identical with the value read off on a good mercurial thermometer placed almost in contact with the pycnometer, provided, of course, neither the temperature of the balance-case nor the height of the meniscus had varied during this interval. The rate of evaporation through so fine a capillary tube is practically nil. This is shown in Table 4, where pycnometer weights for different times are recorded.

TABLE 4.—*Rate of evaporation (transpiration) through capillary stems of the pycnometers.*

Time	$9^h\ 0^m$	$9^h\ 30^m$	$10^h\ 10^m$	$12^h\ 0^m$	$1^h\ 0^m$	$1^h\ 0^m$	$2^h\ 20^m$
Meniscus	2.20	2.15	2.15	2.30	2.30	1.90	2.10
Weight of pycnometer	16.25622	16.25630	16.25622	16.25625	16.25622	16.25560	16.25558

These pycnometers were, therefore, virtually thermometers, and 1 cm. of the stem of the instrument used corresponded to about a degree. Great care must be taken to have the stem thoroughly well ground into the neck of the flask; otherwise water escapes here at a rate sufficiently large to vitiate the present method of measurement. The stopper-error, finally, is so small that where a room of constant temperature is available the results may be relied upon to a few one-thousandths per cent. When temperature fluctuates, as in an ordinary room, the accuracy decreases rapidly to a few one-hundredths per cent.

In operating with iron and steel a source of error is introduced by the fact that the wires are liable to rust.[1] The pycnometer soon shows the yellow color of the hydrate. It is necessary, therefore, not only to rinse the apparatus frequently with hydrochloric acid, but to scour the wire with fine emery paper before each measurement. When so many as 70 wires come to a batch this is excessively tedious, but nevertheless unavoidable. Frequent rinsing with ether is also desirable to remove particles of grease which may collect in the flask.[2]

In the tables, Δ_0 denotes the density of steel at 0° centigrade, v_0 the corresponding volume of the unit of mass.

Measurement of resistance.—To measure the resistances of the short lengths of wire (3 cm.) we constructed an especial apparatus based on Matthiessen and Hockins' principle. A series of folding parallel arms pressed the pieces of steel firmly down upon flat plates of brass properly connected with a bridge. Resistances of constant lengths were always taken with results correct to 1 per cent. Further description of the apparatus and method will be given later.

In the tables the resistance between opposite faces of a cubic centimeter, in microhms, at 0° C., will be denoted by s_0.

To co-ordinate the values for resistance and density—*i. e.*, in order to obtain pairs of data referable, as it were, to the same steel rod—we proceeded thus: The central piece (3 cm.) of the homogeneous portion of each rod was reserved for the resistance measurement; the remainder of the rod furnished the pieces for the density measurement. During the annealing all the pieces were exposed in like manner. In the case of thin rods this method becomes very tedious; for instance, when operating with rods Nos. 21–29, it was necessary to break 9 rods, of 30 cm. each, in order to obtain sufficient material for the density work. Nine measurements of resistance were therefore to be made for each measurement of density; our reasons for avoiding the use of very fine steel wire are therefore apparent.

Method of annealing.—At low temperatures ($<400°$), the usual vapor and metallic baths were used for annealing; at high temperatures, the steel wires were either exposed in an "annealer" or other similar processes were resorted to. The "annealer" is a T-shaped apparatus made of gas-pipe, with a very short horizontal (9 cm.) but long vertical shank (37 cm.). The wires to be annealed, after having been wrapped in many layers of copper foil, or at very high temperatures in platinum foil, alternating with layers of iron wire, are symmetrically introduced into the former (short) shank. This is then closed by a screw-cap at each end. All waste space is filled with iron filings. Into the vertical shank we inserted an insulated thermo-element of known constants, so adjusted that the hot junction just touched the fascicle of steel wires. To insure slow heating and cooling, we surrounded the T of the "annealer" by a layer of carded asbestus (5 cm. thick), and then heated it to the desired temperature in a muffle furnace. The object of the whole arrangement is to *avoid oxidation* as much as possible during the annealing.[1] In the apparatus used, bright steel heated for one hour at white heat remained bright. The accurately circular section of the wires was therefore never sacrificed by the exposure. In one instance where the temperature was accidentally chosen so high as to fuse the copper envelope, this was sucked up into the capillary interstices between the wires, forming a mass which, after cooling, was soldered throughout and compact. For our highest temperatures it was not expedient to use the "annealer." The wires were then wrapped in asbestus paper and heated in a closed crucible filled with iron filings. In these cases slight oxidation was unavoidable. We therefore carefully removed the surface and repolished the wires before each measurement.

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[1] The use of liquids other than water is not advisable.

[2] The cautious use of grease in fitting stopper to flask is indispensable.

Experimental results.—Tables 5 and 6 of the following series contain the results of introductory experiments. They were obtained by a direct process, the large masses of steel being weighed in water. l expresses the length, ρ the radius, μ the mass of the cylinders employed. The density, Δ_t, was observed at t°; Δ_0, and the specific volume v_0, are calculated for 0° C.

TABLE 5.—*Density of rod No. I. Direct method.*

[l=5.35 cm. ρ=0.05 cm.]

μ	Temper.	t	Δ_t	Δ_0	Mean Δ_0	v_0	Remarks.
119.9336	Commercial, soft..........	° 18.1 18.4	7.8325 7.8318	7.8375 7.8368	7.8372	0.12760	
119.6381	Glass hard, 25°, ∞	14.7 15.6	7.8050 7.8046	7.8092 7.8091	7.8092	0.12805	
119.5820	Annealed, 100°, 1^h (steam).	17.7	7.8038	7.8088	7.8088	0.12806	
119.5759	Annealed, 100°, 4^h (steam).	23.5 23.8	7.8030 7.8028	7.8095 7.8094	7.8094	0.12805	
119.5683	Annealed, 100°, 8^h (steam).	17.4 16.5	7.8059 7.8062	7.8108 7.8108	7.8108	0.12803	
119.5676	Annealed, 100°, 12^h (steam)	23.3	7.8049	7.8114	7.8114	0.12802	
119.5662	Annealed, 200°, 30^m (camphor).	24.7 24.7	7.8028 7.8025	7.8097 7.8094	7.8096	0.12805	This and the following observations made 2½ years after the above.
119.5140	Annealed, 330°, 5^m (lead) ..	23.8 23.8	7.8168 7.8171	7.8234 7.8237	7.8236	0.12782	
119.3952	Annealed, 620°, 5^m (lead) ..	24.1 24.1	7.8277 7.8275	7.8343 7.8341	7.8342	0.12765	Rod not covered during exposure.
118.4945	Annealed, 805°, 30^m (lead) .	20.9 21.0	7.8297 7.8309	7.8355 7.8367	7.8361	0.12762	Rod wrapped in asbestus paper during exposure.
117.8363	Annealed (1,300°)	21.0 21.3	7.8406 7.8409	7.8464 7.8467	7.8465	0.12744	Rod wrapped in asbestus paper, surrounded with iron filings, exposed in closed crucible.

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[1] The method of wrapping up the sample in foil we owe to Kohlrausch.

TABLE 6.—*Density of rod No. II. Direct method.*

[l=10.11 cm.; ρ=0.288 cm.]

μ	Temper.	t °	Δ_t	Δ_0	Mean Δ_0	v_0	Remarks.
20.0971	Commercial, soft	19.6	7.6979	7.7033	7.7023	0.12981	
20.0348	Glass hard, 25°, ∞	19.0 19.6	7.6144 7.6147	7.6197 7.6202	7.6200	0.13123	
20.0330	Annealed, 190°, 4^m (aniline)	25.2 25.3	7.6470 7.6476	7.6539 7.6545	7.6542	0.13065	
20.0268	Annealed, 330°, 2^m (lead)	25.0 25.0	7.6586 7.6598	7.6655 7.6667	7.6661	0.13044	
19.9674	Annealed, 645° (lead)	21.4 21.5	7.6967 7.6932	7.7025 7.6991	7.7008	0.12986	Rod wrapped in asbestus paper during exposure.
19.8476	Annealed, 830° (lead)	22.1 22.2	7.7111 7.7108	7.7172 7.7169	7.7170	0.12958	Do.
19.2113	Annealed (1,300°)	22.0 22.1	7.7326 7.7337	7.7387 7.7398	7.7392	0.12922	Rod wrapped in asbestus paper, surrounded with iron filings, exposed in a closed crucible.

In Tables 7, 9, 11 the densities (Δ_t, Δ_0) contained were determined by the aid of the pycnometers above described. In other respects the remarks made with reference to Tables 5 and 6 apply here. q is used as the symbol of section. q (s) denotes the section of the rod when soft, q (h) the section of the same rod hard. The temper was imparted by heating with the electric current and then quenching (p. 30).

Tables 8, 10, 12 contain values for specific resistance s, and correspond to Tables 7, 9, 11, respectively. s_t is observed at t^0; s_0 calculated for 0° C. by aid of the coefficient α. The column r_t, finally, shows the resistance in microhms per centimeter of wire.

We may remark that rods Nos. 21 to 29 and Nos. 30 to 36, rods Nos. 55 to 60 and Nos. 61 to 63, are of like kind and origin.

TABLE 7.—*Density of the rods Nos.* 61 *to* 63. *Pycnometer.*

[Twenty-one pieces: q_0 (s) = 0.01268; q_0 (h) = 0.01257. Mean l = 2.5 cm.; mean ρ = 0.0634 cm.]

μ	Temper.	t °	Δ_t	Δ_0	Mean Δ_0	v_0	Remarks.
11.8068	Commercial, soft	24.1 24.0	7.7227 7.7315	7.7293 7.7381	7.7337	0.12931	Data obtained with Nos. 55–60.
6.2323	Glass hard, 25°, ∞	26.1 26.0	7.6610 7.6622	7.6682 7.6694	7.6688	0.13040	
6.2301	Annealed, 100°, 9^h (steam)	27.4 27.5	7.6821 7.6981	7.6896 7.7056	7.6976	0.12991	
6.2293	Annealed, 200°, 2^m (paraffine).	24.6 24.8	7.6934 7.6890	7.7003 7.6959	7.6981	0.12990	
6.2289	Annealed, 200°, 30^m (camphor).	23.2 23.5	7.6964 7.6969	7.7028 7.7033	7.7030	0.12982	
6.2274	Annealed, 330°, 30^m (lead)	23.4 23.5 23.8	7.7103 7.7228 7.7117	7.7168 7.7293 7.7183	7.7215	0.12951	Wires in the annealer.

TABLE 7.—*Density of the rods Nos.* 61 *to* 63. *Pyenometer*—Continued.

μ	Temper.	t	Δ_t	Δ_0	Mean Δ_0	v_0	Remarks.
		°					
6.2215	Annealed, 810°, 30^m (lead).	24.3 24.5	7.7798 7.7815	7.7864 7.7881	7.7872	0.12842	Wires in the annealer.
6.2140	Annealed (1,000°)	24.4 24.6	7.7818 7.7779	7.7884 7.7845	7.7865	0.12843	Wires in the annealer cooled quick from the high temperature.
6.2085	Annealed (1,300°)	25.1 25.1	7.7933 7.7943	7.8002 7.8012	7.8007	0.12819	Wires in asbestus paper, surrounded with iron filings, exposed in a closed crucible.

TABLE 8.—*Specific resistances of the rods Nos.* 61 *to* 63, *corresponding to the above values, Table* 7.

Nos.	Temper.	r_t	t	s_t	α	s_0	Mean s_0.
			°				
55 to 60	Commercial, soft	1,330	26	16.8	0.0038	15.2	15.25
		1,340	26	16.9	38	15.3	
		1,330	26	16.8	38	15.2	
61 to 63	Glass-hard, 25°, ∞	3,590	26	45.3	0.0016	43.6	43.29
		3,560	26	44.9	16	43.2	
		3,540	26	44.6	16	43.0	
61 to 63	Annealed, 100°, 9^h	2,960	28	37.4	0.0019	35.6	35.61
		2,950	28	37.3	19	35.5	
		2,970	28	37.5	19	35.7	
61 to 63	Annealed, 200°, 2^m	2,750	22	34.7	0.0021	33.2	33.11
		2,740	22	34.6	21	33.1	
		2,730	22	34.5	21	33.0	
61 to 63	Annealed, 200°, 30^m	2,420	23	30.6	0.0024	29.0	28.76
		2,380	23	30.1	24	28.5	
		2,400	23	30.3	24	28.8	
61 to 63	Annealed, 330°, 30^m	1,760	24	22.3	0.0032	20.6	20.61
		1,760	24	22.3	32	20.6	
		1,750	24	22.2	32	20.5	
61 to 63	Annealed, 810°, 30^m	1,570	25	19.8	0.0034	18.2	18.10
		1,560	25	19.7	34	18.1	
		1,550	25	19.6	34	18.0	
61 to 63	Annealed (1,000°)	1,670	24	21.2	0.0033	19.6	19.74
		1,680	24	21.3	33	19.7	
		1,700	24	21.5	33	19.9	
61 to 63	Annealed (1,300°)	1,680	25	21.2	0.0033	19.6	19.29
		1,640	25	20.7	33	19.1	
		1,640	25	20.7	33	19.1	

TABLE 9.—*Density of the rods Nos.* 0

[Eighteen pieces: $q_0(s)=0.03904$; $q_0(h)=0.03955$. Mean, $l=3.0$ cm.; mean, $\rho=0.112$ cm.]

μ	Temper.	t °	Δ_t	Δ_0	Mean Δ_0	v_0	Remarks.
25.2323	Commercial, soft	21.0	7.806	7.812	7.812	0.12801	Early value. Large pycnometer used.
14.3778	Glass hard, 25°, ∞	20.8	7.6759	7.6817	7.6817	0.13018	19 pieces.
		20.8	7.6759	7.6817			
13.7039	Annealed, 100°, 10^{m} (steam)	25.1	7.6881	7.6950	7.6943	0.12997	18 pieces.
		25.5	7.6867	7.6938			
—	Annealed, 100°, 7^{h} (steam)	25.6	7.7032	7.7104	7.7102	0.12970	
		26.0	7.7027	7.7099			
13.6984	Annealed, 190°, 15^{m} (aniline)	26.1	7.7172	7.7244	7.7251	0.12945	
		26.3	7.7186	7.7258			
13.6966	Annealed, 330°, 8^{m} (lead)	26.1	7.7348	7.7420	7.7441	0.12913	
		25.9	7.7390	7.7462			
13.6927	Annealed, 460°, 1^{h} (lead)	24.5	7.7570	7.7638	7.7641	0.12880	Wires in the annealer.
		24.4	7.7576	7.7644			
13.6773	Annealed, 726°	24.6	7.7720	7.7789	7.7793	0.12854	Wires in the annealer. Copper foil.
		24.7	7.7729	7.7798			
13.6682	Annealed (900°)	26.9	7.7733	7.7808	7.7840	0.12846	Do.
		27.2	7.7808	7.7883			
		27.3	7.7756	7.7831			
13.5855	Annealed (1,100°)	28.3	7.7768	7.7846	7.7865	0.12843	Wires in the annealer. Platinum foil.
		28.1	7.7820	7.7898			
		28.2	7.7773	7.7851			
13.5636	Annealed (1,300°)	25.2	7.7781	7.7862	7.7856	0.12844	Wires wrapped in platinum foil, surrounded with iron filings exposed in a closed crucible.
		25.3	7.7793	7.7850			

TABLE 10.—*Specific resistances of the rods Nos.* 0, *corresponding to the above values, Table* 9.

Temper.	r_t	t c	s_t	a	s_0	Mean s_0
Annealed, 460, 1^{h}	502	27	20.1	0.0034	18.4	18.27
	502	27	20.1	34	18.4	
	493	27	19.8	34	18.0	
Annealed, 720°	471	24	18.9	0.0035	17.4	17.13
	462	24	18.5	35	17.0	
	462	24	18.5	35	17.0	
Annealed, 900°	499	28	20.0	0.0034	18.3	18.10
	490	28	19.7	34	18.0	
	490	28	19.7	34	18.0	
Annealed, 1,100°	510	28	20.5	0.0034	18.7	18.60
	510	28	20.5	34	18.7	
	501	28	20.1	34	18.4	
Annealed, 1,300°	501	25	20.1	0.0033	18.5	18.30
	510	25	20.5	33	18.9	
	474	25	19.0	33	17.5	

TABLE 11.—*Density of the rods Nos.* 21 *to* 29. *Pycnometer.*

[Seventy-two pieces: $q_0\ (s) = 0.00523$; $q_0\ (h) = 0.00516$. Mean, $l =$ 2.5 cm.; mean, $\rho = 0.0407$ cm.]

μ	Temper.	t	Δ_t	Δ_0	Mean Δ_0	v_0	Remarks.
7. 4670	Commercial, soft..........	° 25. 9 25. 6	7. 7177 7. 7215	7. 7249 7. 7287	7. 7268	0. 12942	Nos. 30–36.
8. 4014	Glass hard, 25°, ∞	25. 3 26. 3 27. 5	7. 6472 7. 6490 7. 6467	7. 6540 7. 6561 7. 6540	7. 6547	0. 13064	
8. 4014	Annealed, 100°, 1^h (steam) .	29. 3 29. 8 28. 9 30. 0	7. 6576 7. 6575 7. 6605 7. 6581	7. 6656 7. 6658 7. 6685 7. 6664	7. 6666	0. 13044	
	Annealed, 100°, 13^h (steam) .	25. 0 25. 4	7. 6677 7. 6676	7. 6746 7. 6745	7. 6745	0. 13030	
8. 4001	Annealed, 190°, 40^m (aniline)	26. 8 26. 9	7. 6770 7. 6761	7. 6845 7. 6836	7. 6841	0. 13014	
8. 3993 8. 2811 — 8. 2819	Annealed, 190°, 3^h 30^m (aniline).	26. 4	7. 6733	7. 6808	7. 6808	0. 13020	72 pieces.
		27. 1 27. 4 27. 4	7. 6670 7. 6695 7. 6655	7. 6745 7. 6770 7. 6730	7. 6748	0. 13030	71 pieces, one rod lost.
8. 2812 8. 2815	Annealed, 330°, 10^m (lead) .	27. 6 27. 4	7. 6737 7. 6701	7. 6813 7. 6800	7. 6806	0. 13020	Wires in the annealer.
8. 2807	Annealed, 470° (lead)	25. 0 25. 2	7. 7123 7. 7119	7. 7192 7. 7188	7. 7190	0. 12955	Do.
8. 2829	Annealed, 530° (lead)	26. 0 25. 9	7. 7160 7. 7149	7. 7232 7. 7221	7. 7227	0. 12949	Do.
8. 2848	Annealed, 690°.............	24. 3 24. 0	7. 7210 7. 7201	7. 7276 7. 7267	7. 7272	0. 12941	Wires in the annealer. Quick cooling.
8. 2705 8. 2519	Annealed, 810°............	25. 5 25. 5 25. 6	7. 7509 7. 7540 7. 7500	7. 7579 7. 7610 7. 7570	7. 7586	0. 12889	Wires in the annealer; copper foil; slower cooling.
8. 2445	Annealed, 1000°...........	25. 4 25. 3 25. 5	7. 7612 7. 7629 7. 7640	7. 7682 7. 7690 7. 7710	7. 7705	0. 12869	Wires in the annealer; copper foil; slower cooling; weight decreases without perceptible oxidation.

TABLE 12.—*Specific resistances of the rods Nos.* 21 *to* 29, *corresponding to the above values, Table* 11.

Nos.	Temper.	r_t	t °	s_t	a	s_0	Mean s_0.
30 to 36	Commercial, soft	3,458	22	17.8	0.0036	16.5	16.27
		3,415	22	17.6	36	16.3	
		3,405	22	17.0	36	16.2	
21 to 23	Glasshard, 25°, ∞	8,988	27	46.4	0.0016	44.5	43.86
		8,896	27	45.9	16	44.1	
		8,750	27	45.1	16	43.4	
24 to 26	......do	9,116	27	47.0	15	45.3	
		9,062	27	46.8	15	45.0	
		8,614	27	44.4	17	42.6	
27 to 29	......do	8,738	27	45.1	16	43.3	
		8,738	27	45.1	16	43.3	
		8,724	27	45.0	16	43.2	
21 to 23	Annealed, 100°, 1^h	8,162	31	42.1	0.0017	40.1	39.26
		8,013	31	41.4	18	39.3	
		7,890	31	40.7	18	38.7	
24 to 26	......do	8,258	30	42.6	17	40.7	
		8,234	30	42.5	17	40.6	
		7,763	30	40.1	18	38.1	
27 to 29	......do	7,901	30	40.8	18	38.8	
		7,863	30	40.6	18	38.6	
		7,825	30	40.4	18	38.4	
21 to 23	Annealed, 100°, 13^h..........	7,392	24	38.2	0.0019	36.6	35.51
		7,238	24	37.4	19	35.9	
		7,062	24	36.4	20	34.9	
24 to 26	......do	7,485	25	38.6	19	37.1	
		7,385	25	38.1	19	36.6	
		6,965	25	35.9	20	34.4	
27 to 29	......do	7,057	26	36.4	20	34.8	
		7,057	26	36.4	20	34.8	
		6,993	26	36.1	20	34.5	
21 to 23	Annealed, 190°, 40^m.........	6,427	27	33.2	0.0021	31.6	30.82
		6,301	27	32.5	22	30.9	
		6,174	27	31.9	22	30.3	
24 to 26	......do	6,584	27	34.0	21	32.4	
		6,503	27	33.6	21	32.0	
		6,145	27	31.7	22	30.1	
27 to 29	......do	6,159	27	31.8	22	30.2	
		6,124	27	31.6	22	30.0	
		6,112	27	31.5	22	30.0	
21 to 23	Annealed, 190°, 3^h, 30^m.....	5,707	28	29.5	0.0025	27.5	27.10
		5,617	28	29.0	25	27.1	
		5,494	28	28.4	26	26.4	
24 to 26	......do	5,942	27	30.7	23	28.8	
		5,800	27	29.9	24	28.1	
		5,471	27	28.2	26	26.3	
27 to 29	......do	5,536	27	28.6	25	26.7	
		5,512	27	28.4	26	26.6	
		5,450	27	28.1	26	26.3	
21 to 23	Annealed, 330°, 10^m..........	4,361	27	22.5	0.0032	20.6	
		4,328	27	22.3	32	20.5	
		4,296	27	22.2	32	20.3	

TABLE 12.—*Specific resistances of the rods Nos. 21 to 29, &c.*—Continued.

Nos.	Temper.	r_t	t °	s_t	a	s_0	Mean s
24 to 26	Annealed, 330°, 10ᵐ	4, 539	28	23. 4	31	21. 5	20. 68
		4, 419	28	23. 2	31	21. 3	
		4, 295	28	22. 2	32	20. 3	
27 to 29	......do	4, 376	28	22. 6	32	20. 7	
		4, 365	28	22. 5	32	20. 6	
		4, 308	28	22. 2	32	20. 4	
21 to 23	Annealed, 470°..............	3, 883	25	20. 0	0. 0034	18. 4	18. 36
		3, 873	25	20. 0	34	18. 3	
		3, 831	25	19. 8	34	18. 1	
24 to 26	......do	4, 057	26	20. 9	33	19. 2	
		4, 003	26	20. 7	33	18. 9	
		3, 842	26	19. 8	34	18. 2	
27 to 29	......do	3, 922	26	20. 2	34	18. 5	
		3, 909	26	20. 1	34	18. 4	
		3, 847	26	19. 8	34	18. 2	
21 to 23	Annealed, 530°	3, 809	25	19. 7	0. 0034	18. 1	18. 17
		3, 789	25	19. 6	34	18. 0	
		3, 737	25	19. 3	35	17. 7	
24 to 26	......do	4, 052	25	20. 9	33	19. 3	
		3, 924	25	20. 3	34	18. 6	
		3, 732	25	19. 3	35	17. 7	
27 to 29	......do	3, 845	25	19. 8	34	18. 2	
		3, 813	25	19. 7	34	18. 1	
		3, 781	25	19. 5	34	17. 9	
21 to 23	Annealed, 690°..............	3, 630	25	18. 7	0. 0035	17. 2	17. 24
		3, 589	25	18. 5	35	17. 0	
		3, 548	25	18. 3	36	16. 7	
24 to 26	......do	3, 847	25	19. 9	34	18. 2	
		3, 759	25	19. 4	35	17. 8	
		3, 507	25	18. 1	36	16. 5	
27 to 29	......do	3, 686	25	19. 0	35	17. 4	
		3, 654	25	18. 9	35	17. 3	
		3, 580	25	18. 5	35	16. 9	
21 to 23	Annealed, 810°..............	3, 686	26	19. 0	0. 0035	17. 4	17. 56
		3, 676	26	19. 0	35	17. 3	
		3, 646	26	18. 8	35	17. 2	
24 to 26	......do	3, 882	26	20. 0	34	18. 3	
		3, 841	26	19. 8	34	18. 2	
		3, 643	26	18. 8	35	17. 2	
27 to 29	......do	3, 738	26	19. 3	35	17. 6	
		3, 696	26	19. 1	35	17. 4	
		3, 696	26	19. 1	35	17. 4	
21 to 23	Annealed, 1,000°............	3, 935	25	20. 3	0. 0034	18. 7	18. 59
		3, 903	25	20. 1	34	18. 5	
		3, 862	25	19. 9	34	18. 3	
24 to 26	......do	4, 069	25	21. 0	33	19. 4	
		4, 016	25	20. 7	33	19. 1	
		3, 889	25	20. 1	34	18. 5	
27 to 29	......do	3, 923	25	20. 2	34	18. 6	
		3, 860	25	19. 9	34	18. 3	
		3, 785	25	19. 5	34	18. 0	
21 to 29	Annealed, *1,170°	....	....	......	....	....	....

* Fusion of the copper envelope destroys the wires.

In view of the curious increase of resistance observed in wires annealed at high temperatures ($>800°$)—an increase unaccompanied by a corresponding change in the sign of the density-effect, and under no circumstances attributable to variation of section—we thought it desirable to make a series of special *direct* comparisons between steel wires so annealed and wires of the same kind in the commercial soft state. All constants, including the sections of the individual wires, were measured anew. We give the data in Table 13, adding also the earlier values for q_0 and s_0 contained in the tables above. Mere inspection of Table 13 shows that the difference between the present and the early values of s_0, after allowing for the different values of q involved, are wholly within the unavoidable errors of observation. The two sets of data are therefore in good accordance.

TABLE 13.—*Direct comparison of resistances, "soft" (Nos.* 61 *to* 63) *and "commercial, soft" (Nos.* 55 *to* 60).

[Nos. 61 to 63, $\rho = 0.0634$ cm.; $q = 0.01263$. Nos. 55 to 60, $\rho = 0.0635$ cm.; $q = 0.01266$.]

Nos.	Temper.	r_t	s_t	t	a	s_0	Mean s_0	Early values.*	
								s_0	q
				°					
61 to 63.	Annealed (1,300°), cooled slowly.	1,648	20.80	26	0.0033	19.18	19.13	19.3	0.01263
		1,638	20.68	26	33	19.07			
		1,645	20.76	26	33	19.15			
55 to 60.	Commercial, soft	1,349	17.09	26	0.0038	15.54	15.52	15.3	0.01263
		1,362	17.26	26	38	15.68			
		1,333	16.88	26	38	15.35			

* Date of present values: September 3, 1885; date of early values: June 30, 1885.

In Table 14 we cite certain special results for the diameters of wires No. 0 in the glass-hard state and after softening. The differences are readily accounted for, being referable to the volume-increase due to tempering. The diminution of diameter due to oxidation must therefore be less than 0.2 per cent.

TABLE 14.—*Diameters* (2ρ) *of the rods Nos.* 0, *glass hard and soft.*

	2ρ	2ρ	2ρ	Mean 2ρ.
Glass hard.........cm..	0.2250	0.2240	0.2240	0.2243
After annealing at white heat (1,300°).........cm..	0.2230	0.2224	0.2234	0.2229
Sections calculated (Table 16).........cm..	0.2238	0.2228	0.2228	0.2231

Table 15, finally, is constructed to facilitate a comparison of the principal data. Where no values for specific resistances were in hand, the measurements not being feasible, we supplied them by interpolations from our earlier papers on steel. Such values are distinguished by parentheses. The table will be readily intelligible.

TABLE 15.—*General digest. Mean results.*

Nos.	Temper.	s_0	Δ_0	v_0
I. $l=5.3$; $2\rho=1.9$	Commercial soft	(15)	7.8372	0.12760
	Glass hard	(44)	7.8092	0.12805
	Annealed, 100°, 1^h	(39)	7.8088	0.12806
	Annealed, 100°, 4^h	(37)	7.8094	0.12805
	Annealed, 100°, 8^h	(36)	7.8108	0.12803
	Annealed, 100°, 12^h	(36)	7.8114	0.12802
	Annealed, 200°, 30^m	(28)	7.8096	0.12805
	Annealed, 330°, 5^m	(21)	7.8236	0.12782
	Annealed, 620°, 5^m	(18)	7.8342	0.12765
	Annealed, 805°, 30^m	(17)	7.8361	0.12762
	Annealed (1,300°)	(19)	7.8465	0.12744
II. $l=10.11$; $2\rho=0.576$	Commercial soft	(15)	7.7033	0.12981
	Glass hard	(44)	7.6200	0.13123
	Annealed, 190°, 4^m	(32)	7.6542	0.13065
	Annealed, 330°, 2^m	(21)	7.6661	0.13044
	Annealed, 645°	(18)	7.7008	0.12986
	Annealed, 830°	(18)	7.7170	0.12958
	Annealed (1,300°)	(19)	7.7392	0.12922
55 to 60; 61 to 63. 21 pieces. $2\rho=0.127$.	Commercial soft	15.25	7.7337	0.12981
	Glass hard	43.29	7.6688	0.13040
	Annealed, 100°, 9^h	35.61	7.6976	0.12991
	Annealed, 200°, 2^m	33.11	7.6981	0.12990
	Annealed, 200°, 30^m	28.76	7.7030	0.12982
	Annealed, 330°, 30^m	20.61	7.7215	0.12951
	Annealed, 810°, 30^m	18.10	7.7872	0.12842
	Annealed (1,000°)	19.74	7.7865	0.12843
	Annealed (1,300°)	19.29	7.8007	0.12819
0. 18 pieces. $2\rho=0.226$	Commercial soft	(15)	7.81	0.1280
	Glass hard	(44)	7.6817	0.13018
	Annealed, 100°, 10^m	(42)	7.6943	0.12997
	Annealed, 100°, 7^h	(37)	7.7102	0.12970
	Annealed, 190°, 15^m	(31)	7.7251	0.12945
	Annealed, 330°, 8^m	(21)	7.7441	0.12913
	Annealed, 460°, 1^h	18.27	7.7641	0.12880
	Annealed, 720°	17.13	7.7793	0.12854
	Annealed (900°)	18.10	7.7840	0.12846
	Annealed (1,100°)	18.60	7.7865	0.12843
	Annealed (1,300°)	18.30	7.7856	0.12801
30 to 36; 21 to 29. $2\rho=0.081$. 72 pieces.	Commercial soft	16.27	7.7268	0.12942
	Glass hard	43.86	7.6547	0.13064
	Annealed, 100°, 1^h	39.26	7.6666	0.13044
	Annealed, 100°, 13^h	35.51	7.6745	0.13030
	Annealed, 190°, 4^m	30.82	7.6841	0.13014
	Annealed, 190°, 3^h 30^m	27.10	7.6808	0.13020
71 pieces	Do	27.10	7.6748	0.13030
	Annealed, 330°, 10^m	20.68	7.6806	0.13020
	Annealed, 470°	18.36	7.7190	0.12955
	Annealed, 530°	18.17	7.7227	0.12949
	Annealed, 690°	17.24	7.7272	0.12941
	Annealed, 810°	17.56	7.7586	0.12889
	Annealed, 1,000°	18.59	7.7705	0.12869
	Annealed, 1,100°	....	....	....

In certain cases in the above tables it was necessary to interpolate values for the temperature at which wires are annealed, from the known power of the furnace used under given circumstances. All such values have been inclosed in parentheses.

The retrograde movement of density, observed when the rod No. I (see Table 5), thoroughly annealed at 100°, is further annealed at 200°, would seem to indicate the occurrence of shrinkage during the intervening lapse of 2½ years.

Graphic representation.—The results of the above tables are again perspicuously summarized in the graphic comparison, Fig. 1. We remark that the commercial state is distinguished in the diagram by a small *c* attached to the point, and it is to be borne in mind that only in the cases of wires Nos. 21 to 29 and Nos. 61 to 63 were the resistances for this state measured. In the three remaining cases we were obliged to interpolate a value, which was purposely chosen small. Density was always measured.

A few details relative to the figure are here in order. In view of the small variation of density of No. I, we are justified in anticipating a similarly small increment of resistance. It is known that the shortage in such a case is deducted from the variation of the glass-hard state. Hence the five hardest points are so nearly coincident in regard to resistance that the small increment of density in the glass-hard region is quite normal. The points have been spread out laterally in the diagram in order consistently to preserve the method of construction.

While operating with rods Nos. 21 to 29 we were so unfortunate as accidentally to lose one of the 72 pieces (see Table 11). The nature of the variation sought is thus exhibited in two independent phases. Nevertheless we believed ourselves justified in connecting the part of the locus obtained with 72 pieces with the part obtained with 71 pieces directly. The low value (marked *b* in the diagram) for the first of the latter points (annealed 190°, 3^h 30^m) we discard, since insufficient care seems to have been taken in scouring and drying the 71 pieces over again. The difference of mean values for density at this stage of annealing is therefore attributable to an error in the weight for the low value.

DISCUSSION.

Immediate inferences.—If we regard these results as a whole, our first inference is that between the density and the electrical constants of steel there is no immediate connection whatever. Particularly in the case of thin wires, the initially enormous electrical variations correspond to comparatively small changes of density, whereas the latter become marked and striking when the former have nearly subsided. We may divide the whole series of phenomena into two parts or phases: the first part to include those variations which occur between "hard" and "annealed at 350°;" the second part to include the variations between

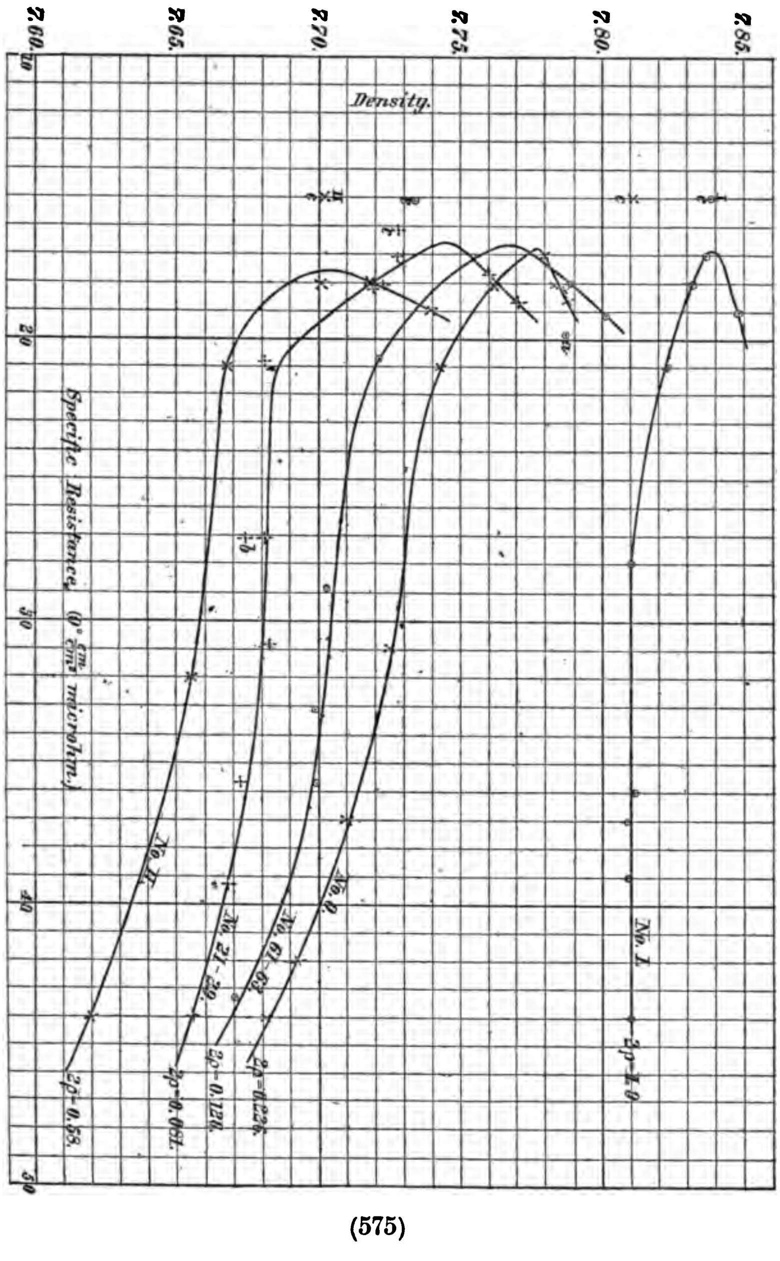

FIG. 1.—Diagram of the relation between the specific electrical resistance and the density of steel in different states of temper.

"350°" and "annealed at white heat." In Table 16 we denote by Δ_s, Δ_{350}, Δ_h, the densities; by s_s, s_{350}, s_h, the resistances corresponding to the "soft," the "annealed at 350°" and the "hard" states, respectively; by Δ_c, s_c, the density and resistance for the commercial states, respectively. The table then gives a concise view of the magnitude of the variations in question.

TABLE 16.—*Relative values of increment of volume and increment of resistance.*

	$-\frac{\Delta_h-\Delta_s}{\Delta_c}$	$-\frac{\Delta_h-\Delta_{350}}{\Delta_c}$	$-\frac{\Delta_{350}-\Delta_s}{\Delta_c}$	$\frac{s_h-s_{350}}{s_c}$	$\frac{s_{350}-s_c}{s_c}$
I	0.0048	0.0018	0.0029	....	....
II	0.0155	0.0060	0.0095	....	....
61 to 63	171	68	103	(1.51)	(0.35)
0	133	80	053	1.53	0.40
21 to 29	150	33	116	1.55	0.29
Mean	0.0131	0.0052	0.0079	....	....

This table substantiates the remarks made. The commercial state has been assumed as a datum simply for want of a better. Commercial wires may be regarded as annealed soft by slow cooling from high temperatures; but unfortunately they always carry a "drawn" strain. The results show that their density is by no means the maximum.

From the table we conclude that as we approach and enter into the region of red heat the density increases at an accelerated rate. It is a plausible surmise which associates this marked change of density with the occurrence of the Cumming-Gore[1] phenomenon of sudden expansion at red heat. Furthermore, we know and readily call to mind here that the temperature to which a rod is heated before sudden cooling and the intensity of hardness resulting are subject to conditions not unlike this. Finally, it is in the neighborhood of the said phenomenon that a marked reconversion of carbon from the combined to the uncombined form is to be looked for. This change may also be regarded as occurring at an accelerated rate, in proportion as Cumming's phenomenon is approached.

Regarding the results from this standpoint, we are urged to refer the first phase, just defined, to mechanical causes. On the other hand, the phenomena comprised within the second phase appear to be largely, if not wholly, induced by chemical causes.

Analysis of the phenomenon.—Of the two dependents on the physical state of steel, density and electrical resistance, the latter is distinguished from the former as being essentially conditioned by the intensity and the kind of strain which the steel rod carries. We may readily conceive a series of rods of like density, but which nevertheless have been strained in thoroughly different ways. The first phase of the above phenomena (annealing between 0° and 350°) is thus elucidated, for we may imagine that within this interval the enormous glass-hard strain gradually subsides. The second phase of the phenomena, however, remains obscure; it is hard to see why so large a change of density is unaccompanied by a corresponding resistance-effect. We may remark, in passing, that the accepted electrical scale is partial to higher degrees of hardness; it blends and crowds the lower degrees. We would probably obtain a better distributer by using the logarithms of resistance constants instead of the mere numbers.

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[1] Gore: Proc. Roy. Soc., XVII, 260, 1869.

The way in which high temperatures act is, therefore, as yet quite obscure. We have failed clearly to discern the laws of such action. There will obviously coexist a number of secondary phenomena, so that the actual result obtained must be regarded as an aggregate of many superimposed effects. It is not remarkable, therefore, that our results fail to corroborate those of Dr. Fromme; that they are here quite at variance with his data; that we were unable to reproduce or to find his maximum density; that our process of annealing did not even force the resistance of the rod back to the small value for the commercial state.

We shall endeavor to enumerate the individual effects which together influence a rod exposed to high temperatures. The more important are: (1) Effect of kind of steel; (2) effect of repeated annealing; (3) effect of long continued heating; (4) effect of oxidation (decarburation); (5) effect of a change in the form or quality of carburation; (6) effect of the rate of cooling.

Among these the first may be dismissed. The different kinds of steel examined show the same behavior. We do not believe that the difference between Dr. Fromme's results and ours is to be ascribed to such a cause. The second point, the effect of repeated heating to a given high temperature, seems to be equally impotent, though we were not at first inclined to regard it so. Wires Nos. 21 to 29 were heated twice to 500°, approximately, without showing any marked difference in density or in electrical state. Long-continued heating, the third point, is known to produce pronounced changes in the degree and quality of carburation of cast iron; but, where the times of exposure amount to only one or two hours and where the quantity of carbon is small, the third effect may also be disregarded. The next point, however, relative to the effect of oxidation (decarburation) in changing the chemical composition of the rod, may be of very serious moment. We have stated that in our principal data no error due to oxidation is to be apprehended. It is improbable, moreover, that carbon should have been transferred by diffusion to the envelope of copper or platinum foil in any appreciable degree, or that gases of any kind should have passed through this envelope to the steel. The inner layers of the copper foil remained bright, although the outer layers were heavily oxidized. In some cases of very high temperature the platinum foil was observed to be dulled or stained where it had been in contact with the steel. Under these circumstances the rods were scoured with unusual care. Indeed, in all cases of possible contamination or corrosion, a sufficient thickness of external layer was removed. · This the results for μ clearly show. In our original experiments, however, in which wires of very low resistance were obtained by the well-known methods of softening, the wires after being treated were invariably oxidized to corrosion. If now we remember that the resistance of a rod is largely dependent on its superficial layers, it is obvious, since decarburation causes the rod to approach nearer iron, that the variation of resistance to be anticipated has the sense of the effect actually observed. The importance of the fifth point, passage of carbon from combined to uncombined, we have no means of estimating. It may be the fundamental cause of the whole series of observed phenomena, and again its effect may be negligible.

To the last of the given points, the effect of the rate of cooling from the high temperature, we are inclined to attach paramount importance. In all the current processes for softening the condition of slow cooling seems to enter essentially. Rods Nos. 61 to 63 were heated to 1,000°, then cooled quickly (but not suddenly). The effect is marked, as is shown by the position of the point *a* in the diagram. The increment of resistance is especially large, and is the same in kind as that produced by sudden cooling. It would appear that to cool a wire in such a way as to leave it quite free from strains of any kind the operation must be conducted with exceeding slowness. Similiar liability to the retention of strains is observed in glass. Our wires were heated in gas-furnaces. The cooling may here be considered complete within two or three hours after the gas is shut off. Chwolson actually heated and cooled his wires in air. It may be plausibly argued, therefore, that the observed minimum of resistance is a secondary phenomenon, and that it is due to the appearance of strain in consequence of comparatively rapid cooling. Thus it becomes plain that the path of the second phase of the above phenomena is subject to pronounced variation, according as the rate at which cooling takes place is either large or small.

Density on the other hand seems to be much less sensitive as regards the rate of cooling. It is possible that with prolonged heating and very prolonged cooling Fromme's maximum may appear. In rods Nos. 0, after annealing at 1,300°, there is an apparent tendency in this direction, but it is so small as to be negligible. So far as the above researches go, the inference is far more probable that, barring effects of decarburation, the density of steel will be greater according as the operation of softening (ausglühen) is more and more carefully conducted; moreover, that for very prolonged cooling the minimum resistance will probably lose its character altogether.

Effect of structure.—Having endeavored to refer the observed relations between density and resistance, in part at least, to effects of stress, we desire finally to call to mind that, even in the case of the simplest elementary relation between these quantities, the aggregate result, when the rods examined are structurally heterogeneous, must necessarily be complex. We remark in passing that it seems to us too early to dismiss the relevant result derived in Bulletin No. 14, viz, the increments of resistance corresponding to a given increment of volume, whether the latter be produced by temper or by temperature, are of the same order. We contend that it is highly improbable that this result should be a mere chance coincidence.[1]

Given a hard rod consisting of p, coaxial, homogeneous, cylindrical shells. Let the right sections, the specific resistances, the specific volumes of these be

$$
\begin{array}{l}
q_1,\ q_2,\ q_3,\ \ldots\ldots\ q_p, \\
\quad s_1,\ s_2,\ s_3,\ \ldots\ldots\ s_p, \\
\qquad v_1,\ v_2,\ v_3,\ \ldots\ldots\ v_p,
\end{array}
$$

respectively. Let Q, S, V be the right section, the specific resistance, the specific volume, respectively, of the rod as a whole.

Suppose we assume that for an elementary homogeneous layer the simple relation which holds approximately for thermal expansion, obtains, viz,

$$s = nv + m \quad \ldots\ldots\ldots\ldots \quad (1)$$

Then, in consequence of (1),

$$S = \frac{Q}{\dfrac{q_1}{nv_1 + m} + \dfrac{q_2}{nv_2 + m} + \ldots\ldots} \quad \ldots\ldots \quad (2)$$

$$V = \frac{Q}{\dfrac{q_1}{v_1} + \dfrac{q_2}{v_2} + \ldots\ldots} \quad \ldots\ldots \quad (3)$$

equations incompatible with

$$S = nV + m$$

except under simple and inadmissible conditions. We advert in this connection to the fact that the observed relation between specific resistance and thermo-electric power is ***independent*** of the structure of the tempered bar. Hence the facility with which its true form is investigated.

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[1] Experiments on the internal structure of tempered steel (now in hand in some number and to be detailed in Bulletin 35, in press) lead to an incidental result which is of importance here. It appears that the immediate effect of decarburation is an increase of the density of the parts decarburized. This agrees with the anomalously large and striking results for the density of low-carbon steel, quite recently discussed by Mr. Miller and Mr. Kent (A. I. M. E., Halifax Meeting, 1885). If at high temperatures carbon may be withdrawn from steel by diffusion without perceptible surface oxidation, it is possible that the importance of the density-effect of decarburation has been underestimated in the text.— March, 1886.

A clear interpretation of the phenomena discussed in this paper will only be possible, therefore, when a series of subsidiary experiments has supplied satisfactory results for the internal structure of tempered steel. Experiments to this end are in progress. The important bearing of the density-relations on problems connected with the maximum of magnetization will be discussed in a subsequent paper.

WASHINGTON—PRAGUE, *September* 9, 1885.

THE RELATION BETWEEN TIME OF EXPOSURE, TEMPER-VALUE, AND COLOR IN OXIDE FILMS ON STEEL.

By C. **Barus** and V. **Strouhal.**

VIEWS REGARDING THE FORMATION OF OXIDE COATS.

The phenomenon.—If a bright steel surface be heated in air to a temperature lying between 200° and 300° it will soon be covered with a film of oxide. The color, and hence we infer the thickness, of this film depends primarily upon the temperature of exposure, and a scale like the following is usually found in technical and metallurgical treatises on the subject:

Very pale yellow	220°
Straw yellow	240°
Brown yellow	260°
Light purple	280°
Dark purple	290°
Clear blue	300°
Pale blue	320°
Blue, tinged with green	330°

It is known, moreover, that the temper of hard steel subjected to the operation of annealing is similarly conditioned. Hence the oxide colors furnish the engineer a datum for the hardness of steel, of great practical utility and importance.

If we endeavor to analyze the physics of this simple and well-known phenomenon of oxidation, we unexpectedly encounter a problem of considerable interest. How are we to explain the fact that after the bright polished surface is jacketed with a protecting film of just finite thickness—a film, moreover, which, from its extreme thinness, we must regard continuous, elastic, tenacious, like scales of glass blown so thin as to be iridescent—further oxidation does not altogether cease? In other words, what is the process by which oxygen passes through the film; or, having decided upon a hypothesis, in how far can we prove it to be compatible with all the observed phenomenon, and in how far are the latter deducible from it?

Cause of oxidation.—With regard to a continuous film, the following consideration is clear at the outset: The outer surface of the film must be and remain oxidized as highly as is possible in air; the inner surface, continually in contact with iron, must be and remain reduced as far as is possible. In other words, if we measure unit of area along the surface of the film, and consider the quantity of oxygen contained in a cylinder with the said unit as a base and an axis normal to the surface of the film, then will the *limit* of the ratio of quantity of oxygen to height of cylinder, when height decreases indefinitely, be a *maximum* near the surface of film in contact with air and a *minimum* for the surface in contact with iron. It is presumable that between these limits the coefficient in question varies continuously. We have in mind, therefore, something very similar to the cause of flow in the mathematical theory of heat — the thermal gradient — and even more similar to the concentration-gradient in the theory of diffusion. In short, the distribution of the degree of oxidation along a normal to the layer is such as to be equivalent to a moving force in virtue of which oxygen is forced through the layer from its external surface to its internal surface. We therefore endeavor to regard the present phenomenon of oxidation as a kind of diffusion.

It is obvious that, with the object of further developing these views, we may enumerate the oxides of iron[1] and then make use either of a hypothesis like that proposed by Grotthus for electrolytic conduction; or, better, a hypothesis based upon the thermal activity of the oxidized molecules. But it is unnecessary to attempt this extension here.

Anticipative electrolytic effect.—A film possessing the properties specified has the essential qualities of an electrolyte. If we suppose one end of a strip of platinum foil or of platinum wire to be in contact with the outer layer of the film, while the other end is in continuous metallic contact (soldered) with the iron or steel, we have all the conditions involved in a galvanic circuit, in which the current passes from iron across the film to the platinum and thence back again to the iron. The electrolyte here is solid; but the possibility of solid electrolytes is by no means unexemplified — indeed, has of late elicited much experimental attention.[2] The efficiency of such an electrolyte is essentially dependent on temperature and on time of action, in a way which we shall presently endeavor to elucidate.

Under circumstances like those in question, electro-motive forces of relatively large intensity have indeed been observed and discussed by Franz,[3] Gaugain,[4] Jenkin,[5] and others. To our knowledge, however, they have invariably been explained as purely *thermo-electric* phenomena, in which the oxide film, kept at a different temperature at its outer and inner surfaces, is the main source of the comparatively large electric effect. The possibility of thermo-currents under these circumstances is indisputable; the possibility of voltaic currents equally so. We apprehend that to separate the one class of currents distinctly from the other is a problem eliciting considerable experimental skill.[1]

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[1] On the composition of different parts of the film in question, see Roscoe and Schorlemmer's Chemistry, II (2), p. 86. Appleton & Co., New York, 1884.

[2] Bidwell: Nature, XXXII, pp. 345, 391, 1885; Thompson: Nature, XXXII, p. 366, 1885.

[3] Franz: Pogg. Ann., LXXXV, p. 388, 1852.

[4] Gaugain: Comptes-Rend., XXXVI, pp. 612–616, 1853.

[5] Jenkin: Rep. Br. Assoc., 1861, (2), p. 34.

Consequences of the theory.—The immediate consequences of the (diffusion) theory assumed are these: The rate at which oxidation takes place is greater as the film is thin; for, since the difference in oxidation of the anterior and posterior faces of the film is constant in value, it follows that the force tending to move oxygen across any interface is smaller in proportion as the film itself is thicker. In consequence of the solid medium, oxidation must cease entirely after a certain definite and limiting depth, dependent on temperature only, has been reached; that the depth and degree of oxidation (time $=\infty$) must increase with temperature, because temperature increases the thermal activity of the oxidized molecules of the film. Indeed, we may here seek to find a crucial difference between solids and liquids, inasmuch as in the former diffusion demonstrably ceases after a certain small thickness is permeated, whereas in liquids, as a result of vastly greater thermal mobility, diffusion is independent of thickness.

Within certain limits, therefore, an oxide film of given color can be obtained in an indefinite number of ways: at comparatively low temperatures, by long intervals of exposure; at relatively high temperatures, by short exposures. Curiously enough, the conditions subject to which a given oxide color appears are strikingly analogous to the conditions subject to which a given degree of temper is imparted to hard steel. It is possible, therefore, that the oxide film may be a criterion for the temper of a rod, *cœteris paribus*, of far greater critical sensitiveness than has hitherto been supposed; though it must first be investigated in what degree and upon what conditions, at a given temperature, the rate and nature of the variation of temper and the rate and nature of the color variation of the oxide film are convertible.

EXPERIMENTAL RESULTS.

Method of experiment.—The experiment which we finally decided upon is of the simplest kind, and yet it is capable of yielding a much larger return than we have thus far derived from it. Indeed, we believe that the method pursued will satisfactorily and crucially answer all the questions involved in the present discussion, except, of course, those referring to electrical currents.

A rectangular parallelopipedon or shaft of iron, 25 cm. high, 5 cm. broad, 5 cm. thick, is placed on a suitable tripod, with its faces vertical. The flame of a chimneyed Bunsen burner impinges against its base. To protect the sides, both from the flame and from direct radiation, a large, thick, horizontal screen of asbestus board is adjusted, about 1 cm. above the bottom of the block. The upper 24 cm. are thus heated by conduction only.

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[1] A few experiments which we made here show the effect in question, but are otherwise not easily explained quantitatively.

This prism or block of iron was purposely chosen massive, *i. e.*, of large section, so that the diminution of temperature from the bottom upward would occur at a small uniform rate throughout. The colors are then ultimately distributed in wide bands. Experiments subsequently showed that the length might have been advantageously chosen two to three times that of the block selected. Insufficient attention (as we also found subsequently) was bestowed upon having the block scrupulously clean before the experiment was commenced; for in the colored surface finger-prints, for instance, could be distinctly discerned, the color at such spots always preceding, in degree, that of the untarnished surface of the bar. Thus the color bands, after long annealing, are liable to become distorted, oblique, and ill-defined. It is then difficult to obtain satisfactory measurements.

We may remark here that in using this block for obtaining the temper value of an oxide color two methods suggest themselves:

(1) We may produce a satisfactory succession of colors on the surface of the iron block by heating one end as described; provide these with an arbitrary fixed scale, something like Bunsen and Kirchhoff's spectroscopic scale; refer the color of hard steel wires annealed by exposure to air of known temperature during known time to the datum on this scale; finally, compare this value with the thermo-electric hardness of the wire, measured directly.

(2) Or we may drill into the bar narrow vertical holes closed at the lower end but extending to within a few millimeters of the base. Into these introduce the hard steel wire; compare the color bands between given isothermals on the surface of the block with the resistances of the parts of the steel rod comprehended between the same isothermals, respectively, by the aid of a Matthiessen-Hockin rider of 1 cm. length. The block is of course not to be heated until the steel wires are introduced. Both methods are in progress.

After the thermal flow has become stationary, temperature is distributed along the axis of the block in accordance with the well-known relation $t_1 + t_3 \mid t_2$, = const., where t_1, t_2, t_3 are the temperatures of any three consecutive equidistant points. Three measurements, therefore, enable us to interpolate the thermal state for any point of the block. Our values for temperature are determined thermo-electrically by aid of a couple of platinum and platinum-iridium alloy of known constants. The junction of this was hammered flat. During the exploration a brass clamp, one end of which was covered with asbestos felting, held the flat junction firmly against the part of the block to be examined.

Results.—In the Tables 1 to 5 which accompany the following protocol, e_{20} denotes the electromotive force (micro-volts) observed when the temperature of the cold junction of the thermo-couple is 20° C.; *T* is the corresponding temperature of the hot junction; *d* refers to the position or depth (cm.) of the adjoining temperature below the top of the block as a datum. Sometimes, to show the constancy of the distribution, the *times* at which the observations were respectively made are also annotated. Throughout the experiment the bottom of the block remains dark at a temperature of about 400°.

Tuesday, May 26, 1885 — 0 hour.

Experiment commenced. Flame ignited at 10^h a. m. Clear blue zone, 25 cm. *deep*, i. e., 25 cm. below the top plane of block.

12 hours.

Clear blue zone, 22 cm. deep. Top not observably colored.

Wednesday, May 27, 1885 — 24 hours.

Clear blue zone, 18 cm. deep. Top, straw yellow. The surface is mottled. Rough places, cracks, edges, color blue long before the surface is perceptibly colored at all. Finger-prints especially apparent.

36 hours.

Clear blue zone, 15 cm. deep. Top, yellow-brown.

TABLE 1.—*Distribution of temperature after* 36^h.

Elem. No.	e_{20}	T	d	*Time.*	Remarks.
		°		h m	
36..........	1,461	190	1	6 20	
	1,461	190	1	26	
	2,400	288	23	6 36	
	2,428	288	23	45	
	1,705	215	12	7 00	
	1,705	215	12	10	
	1,382	185	1	....	Clamp removed; element in mere contact with shaft.
	1,486	193	1	7 15	Clamp again adjusted.
	1,482	192	1	40	
	1,481	192	1	55	

Thursday, May 28, 1885 — 48 hours.

Clear blue zone, 14 cm. deep. Top, dark yellow-brown.

TABLE 2.—*Distribution of temperature after* 48^h.

Elem. No.	e_{20}	T	d
		°	
36........	1,346	175	1

No visible effect during the intervening 12^h, except a widening of the bands. Blue spots near the top, in rough places.

Friday, May 29, 1885—72 hours.

Clear blue zone, 13 cm. deep. Top, brown-purple.

TABLE 3.—*Distribution of temperature after* 72h.

Elem. No.	em	T	d	Remarks.
		°		
26	1,453	189	0	Brown-purple.
	1,606	214	11	Blue.
	2,265	275	22	Steel-gray.
	1,758	224	....	Light blue lower boundary = maximum clear blue.

Bands too jagged for clear definition. Whole upper part of shaft dark brown to light purple, with spots and patches of blue. Cracks and rugosities purple-blue throughout.

Saturday, May 30, 1885 —96 hours.

Clear blue zone, — cm. deep. Top, brown-purple. About as yesterday. Blue zone darker and wider. The white or steel-gray part higher, say 13 cm. There are blue spots on the top of the shaft, but all demarcation confused, so that it is difficult to define accurately.

Sunday, May 31, 1885 — 120 hours.

Clear blue zone, — cm. deep. Top, brown-purple. About as yesterday. Blue zone a little higher. Spots somewhat darker.

Wednesday, June 3, 1885 — 192 hours.

Clear blue zone, 10 cm. deep, Top, brown-purple. Rugosities, edges, cracks, spots, blue. Upper shaft brown purple.

Saturday, June 6, 1885 —264 hours.

Clear blue zone, 8 cm. deep. Top, brown-purple, with lines of blue. Upper shaft brown-purple; spots of blue merging into steel-gray.

Tuesday, June 9, 1885 — 336 hours.

Clear blue zone, 9 cm. deep. Top, brown-purple. Color has visibly intensified, but is hard to define. Definite purple zone, between 9 cm. and 7 cm. deep, is the salient new feature.

Sunday, June 14, 1885 — 456 hours.

Clear blue zone, 8 cm. deep. Top, purple.

TABLE 4.—*Distribution of temperature after* 456h.

Elem. No.	em	T	d	Remarks.
		°		
26	1,376	180	0	Light brown-purple.
	1,621	208	11	Blue.
	2,174	265	22	Black.

The whole upper shaft darker. From the bottom to 4 cm. upward (21 cm. deep), oxidized black, fading into steel-gray.

Tuesday, June 30, 1885 — 840 hours.

Clear blue zone, 8 cm. deep. Top, purple.

TABLE 5.—*Distribution of temperature after* 840^h.

Elem. No.	e_{20}	T	d	Remarks.
		°		
85	1,342	175	1	
	1,452	189	10	
	1,865	233	20	
	1,464	190	....	Mean blue zone.

Distribution of color..	0– 8 cm. deep..	Purple. Blue. Steel-gray.
	10–20 cm. deep....	Steel-gray, tinged with pink and green.
	20–25 cm. deep....	Shades very rapidly into black.

842 hours.

Gas shut off.

848 hours.

The block is just warm to the touch (35° C.), showing that in 5 hours after commencing the heating the thermal condition may be regarded practically stationary.

In Table 6 we give a digest of the different series of measurements for temperature-distribution, together with the mean results for the given interval of 840 hours. The latter are derived by graphic interpolation:

TABLE 6.—*Digest: Temperature* (T) *and depth* (d).

36 hours.		48 hours.		72 hours.		456 hours.		840 hours.		Mean results.	
T	d	T	d	T	d	T	d	T	d	T	d
°		°		°		°		°		°	
190	1	175	1	189	0	180	0	175	1	183	0
215	12	......	....	214	11	208	11	189	10	189	5
288	23	......	....	275	22	265	22	233	20	202	10
......	....	......	....	......	....	......	....	......	....	225	15
......	..	......	....	......	....	......	..	......	....	253	20
......	....	......	....	......	....	......	....	......	....	288	25

The mean results in this table agree as well with the direct measurements for clear blue, &c., as the conditions of measurement permit us to expect.

In Table 7, finally, the fundamental result of the above measurements is concisely summarized. The table contains the time of occurrence, position, and temperature of the blue film during the 840 hours of observation:

TABLE 7.—*Average temperature of the mean "clear blue" band, regarded as a function of time.*

Date.	Hours.	Depth.	Temperature.
			°
May 26, 1885	0	25	(300)
....	12	22	265
May 27, 1885	24	18	241
....	36	15	224
May 28, 1885	48	14	220
May 29, 1885	72	13	215
May 30, 1885	96	....	....
May 31, 1885	120	....	....
June 3, 1885	192	10	204
June 6, 1885	264	9	198
June 9, 1885	336	8	197
June 14, 1885	456	8	196
June 30, 1885	840	8	195

The final table is self-evident.

TABLE 8.—*Variation of color with time at* 185° (*top of brick*).

Time ..	0^h	12^h	24^h	36^h	48^h	72^h	300^h	800^h
Color ..	Colorless.	Not perceptibly colored.	Straw-yellow.	Yellow-brown.	Dark yellow-brown.	Brown-purple.	Purple..	Purple.

An inspection of Table 1 shows that during ordinary intervals of observation (12^h) the thermal distribution over the block may be regarded stationary. Within the very large interval 840 hours, however, fluctuations of temperature as large as 15° for points near the top and even 50° for points very near the base of the shaft are encountered. These are due to unavoidable fluctuations in the intensity of the flame. In taking the mean temperatures for the 35 days, the hurtful effects of these irregularities are satisfactorily eliminated.

Table 1, furthermore, shows the effect of measuring with and without the felted clamp, with a result equivalent to an excess of temperature of about 7° to 8° C. for the latter case. It is obvious that by protecting any point with a non-conducting envelope the temperature at this point soon rises above its normal (stationary temperature) value. Now, no illusory conclusions were to be apprehended for values of temperature too large, whereas values below the normal temperature at any given point would have led the observer into serious errors. We desired to investigate the lowest temperature at which the blue band, for instance, is producible. We saw no great objection to reporting the temperature a little higher than it actually was. It would, however, have been a fatal blow to some of our inferences had this temperature been erroneously measured too low.

Such errors and inaccuracies as have been introduced into the above protocol by distorted, oblique, and jagged bands, we shall in the future endeavor to eliminate by exposing well-polished and scrupulously clean surfaces only.

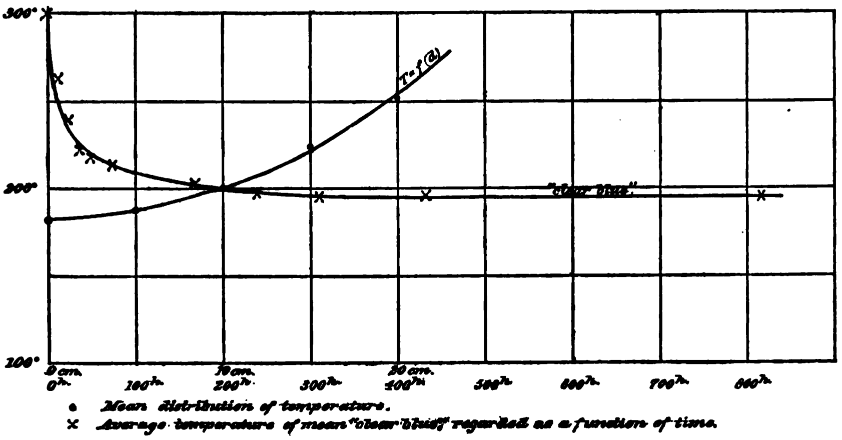
We add, in conclusion, that the original appearance of the shaft (say after 5 hours), with the blue only just emerged above the horizontal asbestus screen, and the final appearance (described under 840 hours in the protocol) are sufficiently in contrast to give pronounced emphasis to the results. We start with the upper shaft bright, the lower colored; we close with the upper shaft colored, the lower bright steel-gray.

DISCUSSION.

Difficulty of measurement.—Unless special optical apparatus be constructed, measurements which attempt to follow the change of position of a color among colors are always unsatisfactory, so far as the data are concerned. To the eye, however, the evidence furnished by such experiments is often strikingly conclusive. This is the case with the color diagram under discussion.

Color, temperature, time.—Our best mode of procedure will be that of first depicting graphically the mean positions of the given temperatures on the shaft, as contained in Table 6. Knowing these and the average depths of the blue band, its mean temperature at any given time follows at once. In Figure 2 we have constructed both the curves under consideration. The first shows a gradual ascent. It has been stated that it was for the purpose of securing this uniformity of slow increase of

Fig. 2.



temperature, and as a consequence wide color bands (blue zone 1 inch and more in width), that a block of large section was selected. Unfortunately the block ends abruptly with 185°, whereas it would have been desirable to terminate the shaft by not more than 50°. These desiderata are available to some extent, however, by lowering the flame or by inserting plates of metal or sheets of asbestus between flame and base of shaft.

The other curve shows exceedingly abrupt descent near the origin; but, as the rate decreases very rapidly, we find that after, say, 200 hours the horizontal asymptote is practically reached. The descent, however, continues at a very slow rate, and it is probably not quite complete even after 1,000 hours. Qualitatively this mode of variation must be very closely analogous to the change of temper actually observed on annealing hard steel. We could not, unfortunately, extend our experiments on the electrical effect of annealing beyond the small interval of about 12 hours of exposure; but from our results it is none the less conclusively deducible that the change of temper produced by annealing in 330° for only one minute is beyond the reach of 185° altogether, even though acting through infinite time. And this is precisely the interpretation of the "clear blue" color curve in Figure 2. Of course it is evident that, in the case of phenomena which owe their existence to and are evoked by causes wholly distinct, complete coincidence throughout their range of occurrence is as good as impossible. But the close resemblance of these two inherently dissimilar variations is the remarkable result which we desire to signalize here. Again, we would conjecture that high temperatures ($>200°$) are instantaneously efficient in contrast with low temperatures ($<200°$) where the effect is produced very gradually at a slowly decreasing rate. For final decision, however, it will be necessary to call further experimental data to our aid.

Conditions of oxidation.—Our second result, immediately deducible from Table 7 or from Figure 6, is this, that for each temperature of annealing (100°–500°) there exists a certain definite color of oxide film for which this temperature is characteristic; that this final color is reached gradually at a rate decreasing continually through infinite time. It follows that the depth to which superficial oxidation (the normal circumstances under discussion presupposed) can penetrate is ultimately a function of temperature only—but a sharply-defined function of temperature. For further elucidation we add that the size of the oxygen atom is to be estimated in fractions of millionths of a millimeter, whereas the depth or thickness of the color film is at least one hundred times the same unit. Hence we may estimate that the mean depth of penetration of an oxygen atom is expressible in thousands of times its own dimensions. We consider this general result relative to the (chemical) diffusion of a gas into a solid important, admitting, as it does, of quantitative discussion. Even if a certain constancy in the color effect of the action of a given temperature on steel has been assumed, this knowledge has been vague at best; its interpretation has been disregarded, and its true nature as a "limit" phenomenon—*i. e.*, the dependence of the temper value of any oxide tint on the temperature and the time of exposure—has, to our knowledge, been conjectured only in an incidental note of our own.[1]

Finally, the permeable depth increases rapidly with the temperature, until at incipient red heat the film is sufficiently thick to be brittle and liable to rupture, whereupon the present phenomenon, as such, ceases or is repeated in irregular succession.

Having endeavored to digest and interpret the experimental data in hand, we return therefore to the views expressed in the early paragraphs of this paper.

WASHINGTON—PRAGUE, *September* 15, 1885.

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[1] United States Geological Survey, Bulletin 14, p. 113, 1885.

MISCELLANEOUS ANALYSES.

MINERALS FROM WASHINGTON, D. C.

In an enlargement of the water supply of Washington, a rock tunnel, four miles long, with several vertical shafts tapping it from the surface, has been constructed. The minerals referred to below were collected at various points along the excavation by Mr. G. P. Merrill, of the United States National Museum, who will in due time publish a full account of them and of their modes of occurrence.

A.—Saussurite from a gabbro found at the east shaft. Analysis by F. W. Clarke.]

Ignition	0.74
SiO_2	45.12
Al_2O_3	30.53
FeO	1.90
CaO	17.34
MgO	0.42
K_2O	1.09
Na_2O	2.02
	99.16

[B.—Hornblende from the same gabbro. Analysis by R. B. Riggs.]

H_2O	1.25
SiO_2	52.42
Al_2O_3	3.15
Fe_2O_3	3.60
FeO	8.36
MnO	0.11
CaO	14.33
MgO	15.85
K_2O	0.12
Na_2O	1.16
	100.35

[C.—Sphene: pale yellow, semi-translucent, imbedded in prochlorite. Sp. gr. 3.45?. Analysis by F. W. Clarke.]

Ignition	0.54
SiO_2	30.10
TiO_2	40.82
CaO	28.08
MgO	0.40
MnO	Trace
	99.94

FAYALITE FROM THE YELLOWSTONE PARK.[1]

[Analysis by F. A. Gooch on only 0.24 gramme of material; 10.36 per cent. of material insoluble in HCl.]

SiO_2 in insoluble part	7.02
SiO_2 in soluble part	25.61
Fe_2O_3	14.92
FeO	51.75
Al_2O_3	Trace
MgO	1.66
CaO	None
Ignition	None
	100.96

SERPENTINE FROM NEWBURYPORT, MASS.

[Analysis by F. W. Clarke.]

H_2O	14.54
SiO_2	41.32
FeO	2.36
MgO	41.49
	99.71

KAOLIN FROM AIKEN, S. C.

[Analysis by F. W. Clarke.]

H_2O	14.10
Al_2O_3	40.25
SiO_2	45.56
	99.91

HORNBLENDE-ANDESITE FROM HAGUE VOLCANO, BOGUSLOFF ISLAND, BEHRING SEA, ALASKA.

Two samples collected by Lieut. G. M. Stoney and petrographically studied by Mr. G. P. Merrill.[2]

[A.—Rock described by Merrill as "consisting of a light-gray, slightly purplish, fine grained and porous groundmass, in which small glassy feldspars and dark brown and green hornblende-like crystals are readily distinguishable by the naked eye." A feldspar separated from it by Thoulet's method had a sp. gr. of 2.7 and contained 55.29 per cent. of silica, which is about the proportion for labradorite. Complete analysis by T. M. Chatard.]

Ignition	0.99
SiO_2	56.07
TiO_2	1.24
Al_2O_3	19.06
Fe_2O_3	5.39
FeO	0.92
MnO	0.23
CaO	7.70
MgO	2.12
P_2O_5	0.16
Na_2O	4.52
K_2O	1.24
	99.64

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[1] Fully described by J. P. Iddings, with crystallographic measurements by S. L. Penfield, in Am. Journ. Sci., July, 1885.

[2] Proc. U. S. Nat. Mus., Vol. VIII, No. 3, April 23, 1885.

[B.—A darker colored rock with a denser groundmass and carrying a larger proportion of microscopic hornblende and feldspar crystals. Analysis by T. M. Chatard.]

	1.	2.	*Mean.*
Ignition	0.34	0.34	0.34
SiO_2	51.46	51.63	51.54
TiO_2	0.32	......	0.32
Al_2O_3	20.26	20.35	20.31
Fe_2O_3	4.64	......	4.64
FeO	3.56	......	3.56
MnO	0.32	0.32	0.32
CaO	9.55	9.56	9.55
MgO	3.16	3.16	3.16
P_2O_5	0.57	......	0.57
K_2O	2.47	......	2.47
Na_2O	4.29	......	4.29
	100.94		101.07

FOUR ERUPTIVE ROCKS FROM NEW MEXICO.

[Collected by Capt. C. E. Dutton.]

[A.—Lava from a cañon on the east side of San Mateo Mountains. Analysis by T. M. Chatard.]

Ignition	0.52
SiO_2	68.40
Al_2O_3	17.99
Fe_2O_3	2.66
FeO	1.63
MnO	0.21
CaO	0.67
MgO	0.49
K_2O	3.54
Na_2O	4.54
	100.65

[B.—Rock from a cañon on the east side of San Mateo Mountains. Analysis by T. M. Chatard.]

Ignition	0.16
SiO_2	65.51
TiO_2	0.92
P_2O_5	0.07
Al_2O_3	16.89
Fe_2O_3	1.41
FeO	2.52
MnO	0.31
CaO	1.19
MgO	0.39
K_2O	5.02
Na_2O	6.42
	100.81

[C.—Rock from 6 miles northeast of Grant's. Analysis by T. M. Chatard.]

H_2O	1.38
$CO_2 = 5.77$ $CaCO_3$	2.56
SiO_2	49.80
TiO_2	2.67
P_2O_5	0.73
Al_2O_3	15.33
FeO. No Fe_2O_3	7.44
MnO	0.30
CaO	7.19
MgO	6.61
K_2O	4.36
Na_2O	2.71
	101.08

[D.—Basalt from 6 miles northeast of Grant's. Analysis by T. M. Chatard.]

H_2O	0.36
SiO_2	47.54
TiO_2	2.76
P_2O_5	0.51
Al_2O_3	16.73
Fe_2O_3	6.69
FeO	6.67
MnO	0.19
BaO	0.03
CaO	8.74
MgO	6.38
Na_2O	2.81
K_2O	1.10
	100.51

An estimation of CO_2 gave 0.30 %; but a part of this was due to the permeability of the platinum tubulated crucible.

DACITE FROM WASHOE, NEVADA.[1]

[From spur northeast of McClellan Peak, near the American Flat Road. Analysis by F. A. Gooch.]

SiO_2	69.96
Al_2O_3	15.79
Fe_2O_3	2.50
CaO	1.73
MgO	0.64
Na_2O	3.80
K_2O	4.12
Ignition	1.53
	100.07

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[1] See Hague and Iddings, Bulletin No. 17, United States Geological Survey.

RHYOLITE FROM WASHOE, NEVADA.[1]

[Locality south-southeast of McClellan Peak. Analysis by F. A. Gooch.]

SiO_2	73.07
Al_2O_3	11.78
Fe_2O_3	2.30
CaO	2.02
MgO	0.39
Na_2O	1.19
K_2O	6.84
Ignition	2.24
	99.83

BLUE OHIO SANDSTONE.

[A building stone from quarries near Cleveland. Analysis by T. M. Chatard.]

SiO_2	91.67
Al_2O_3	6.92
Fe_2O_3	Trace
CaO	0.28
MgO	0.34
Ignition	1.17
	100.38

Insoluble in HCl, 97.50.

SANDSTONE FROM MICHIGAN.

[A yellow sandstone, quarried as a building stone at Stony Point. Analysis by F. W. Clarke.]

SiO_2	84.57
Fe_2O_3	6.48
Al_2O_3	5.90
MgO	0.68
Ignition	1.92
Alkalies	Undet.
	99.55

Insoluble in HCl, 91.87. The portion soluble in HCl contained 6.23 of the ferric oxide. The iron and magnesia are practically all in the cement, but the sand particles contain some silicate of aluminum.

TWO CLAYS FROM HENRY COUNTY, ILLINOIS.

[A.—On burning becomes reddish. Analysis by T. M. Chatard.]

H_2O	15.57
SiO_2	46.12
P_2O_5	0.08
TiO_2	0.79
Al_2O_3	15.24
Fe_2O_3	4.41
MnO	0.28
CaO	8.63
MgO	3.63
K_2O	3.79
Na_2O	1.54
	100.08

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[1] See Hague and Iddings, Bulletin No. 17, United States Geological Survey.

[B.—Burns reddish, but lighter than A. Analysis by T. M. Chatard.]

H_2O	18.64
SiO_2	42.58
P_2O_5	0.10
TiO_2	0.64
Al_2O_3	12.16
Fe_2O_3	3.90
MnO	0.09
CaO	11.33
MgO	4.32
K_2O	3.88
Na_2O	1.96
	99.60

FOUR RESIDUARY CLAYS FROM WISCONSIN.

Collected by Prof. T. C. Chamberlin. Analyses by R. B. Riggs. Material dried at 100°.

[A.—Clay from Dodgeville, 4½ feet below the surface, 4 feet above rock.]

SiO_2	71.13
Al_2O_3	12.50
Fe_2O_3	5.52
FeO	0.45
TiO_2	0.45
P_2O_5	0.02
MnO	0.04
CaO	0.85
MgO	0.38
Na_2O	2.19
K_2O	1.61
H_2O (includes H of organic matter)	4.63
CO_2	0.43
C (in organic matter)	0.19
	100.39

[B.—Same locality, 8½ feet below the surface, in contact with rock.]

SiO_2	49.59
Al_2O_3	18.64
Fe_2O_3	17.19
FeO	0.27
TiO_2	0.28
P_2O_5	0.03
MnO	0.01
CaO	0.93
MgO	0.73
Na_2O	0.80
K_2O	0.93
H_2O (includes organic H)	10.46
CO_2	0.30
C (organic)	0.34
	100.50

[C.—Clay from one mile west of Cobb. 1 foot below the surface, 5½ feet above rock.]

SiO_2	53.09
Al_2O_3	21.43
Fe_2O_3	5.53
FeO	0.56
TiO_2	0.16
P_2O_5	0.03
MnO	0.03
CaO	0.95
MgO	1.43
Na_2O	1.45
K_2O	0.53
H_2O (includes organic H)	14.79
CO_2	0.29
C (organic)	0.22
	100.09

[D.—Same locality as C. 6½ feet below the surface, in contact with rock.]

SiO_2	49.13
Al_2O_3	20.02
Fe_2O_3	11.04
FeO	0.93
TiO_2	0.13
P_2O_5	0.04
MnO	0.06
CaO	1.22
MgO	1.92
Na_2O	1.33
K_2O	1.60
H_2O (includes organic H)	11.72
CO_2	0.39
C (organic)	1.09
	100.62

MARITIME SOILS FROM MASSACHUSETTS.

Seven samples of salt-marsh soils collected by Professor N. S. Shaler. Partial analyses by R. B. Riggs.

[A.—Three soils from Green Harbor River, Marshfield: (1) Reclaimed salt-marsh. Average sample of soil from surface to two feet deep. Planted with onions. (2) Diked land. Average surface sample, second year of tillage. (3) Average sample of marine marsh immediately outside of dike.]

	1.	2.	3.
Carbon of organic matter	3.07	3.67	12.63
$NaCl$	0.36	0.15	6.70
Na_2O	2.43	2.19	2.33
K_2O	1.43	1.09	1.44
P_2O_5	0.17	Undet.	Undet.

[B.—Three soils from marine marsh, Charles River, Mt. Auburn street, Cambridge: (1) Lower portion of eel-grass layer; (2) Middle portion of eel-grass layer; (3) Middle portion of upper layer.]

	1.	2.	3.
Carbon of organic matter	3.88	4.22	12.68
NaCl	2.36	1.80	4.65
Na_2O	2.40	2.10	2.31
K_2O	1.76	1.80	1.89
P_2O_5	0.15	Undet.	0.07
CaO	Undet.	1.51	1.29

[C.—Soil from marine marsh, Mystic River, Malden. Average sample of a section from surface to three feet deep.]

Carbon of organic matter	3.06
NaCl	1.30
Na_2O	2.33
K_2O	1.70

OÖLITIC SAND FROM SHORE OF GREAT SALT LAKE.

Collected by I. C. Russell and analyzed by T. M. Chatard. The material consisted of small spheroidal grains, grayish-white in color, and with an admixture of a few dark particles. Washing with water extracted no sulphates and only traces of chlorides. After treatment with hydrochloric acid, a residue of grains of quartz, clay, and a little organic matter was left.

Insoluble in HCl	4.03
Organic matter	0.27
H_2O	0.83
Fe_2O_3 and Al_2O_3	0.20
CaO	51.33
MgO	0.72
Na_2O and K_2O	0.63
SO_3	0.89
P_2O_5	Trace
CO_2	41.07
	99.97

An impure calcium carbonate.

TWO INCRUSTATIONS FROM NEVADA.

Analyses by T. M. Chatard of the portions soluble in water.

A.—Grayish pulverulent crusts, from the surface of a playa, North Arm of *Old* Walker Lake. One gramme of material yields 0.2978 grm.

of soluble substance, or 29.78 per cent. The latter, analyzed as if it were an independent substance, gave the following results:

		Per cent. of total soluble.	Probable combination.	
By weight.				
SiO_2	0.0058	1.95	SiO_2	0.0058
K	0.0018	0.60	KCl	0.0035
Na	0.1159	38.92	NaCl	0.0075
Cl	0.0063	2.16	$Na_2B_4O_7$	0.0123
SO_4	0.0350	11.75	Na_2SO_4	0.0518
B_4O_7	0.0095	3.19	Na_2CO_3	0.2152
	0.1743			0.2961
CO_3 by difference	0.1235	41.43	99.43 % accounted for.	
	0.2978	100.00		

Or, to express the results in different form, the probable composition may be reckoned into percentages, as follows:

SiO_2	1.96
KCl	1.18
NaCl	2.53
$Na_2B_4O_7$	4.15
Na_2SO_4	17.49
Na_2CO_3	72.69
	100.00

B.—Incrustation from five miles west of Black Rock. One gramme of material gave 0.2310 grm., or 23.10 per cent., soluble in water. The latter, reckoned up to 100 per cent. and analyzed independently as under A, gave results as follows:

		Per cent. of total soluble.	Probable combination.		
By weight.			*By weight.*		*By percentage.*
SiO_2	0.0050	2.16	SiO_2	0.0050	2.18
K	0.0017	0.74	KCl	0.0032	1.39
Na	0.0832	36.02	NaCl	0.1362	59.32
Cl	0.0841	36.40	$Na_2B_4O_7$	0.0023	1.00
SO_4	0.0420	18.18	Na_2SO_4	0.0621	27.05
B_4O_7	0.0018	0.78	Na_2CO_3	0.0208	9.06
	0.2178			0.2296	100.00
CO_3, by difference	0.0132	5.72	99.43 % of the original 0.2310.		
	0.2310	100 00			

MARL FROM WA KEENEY, TREGO COUNTY, KANSAS.

[From a large deposit found near the surface. Analysis by F. W. Clarke.]

H_2O	1.77
CO_2	35.03
SiO_2	14.06
Fe_2O_3	5.10
MgO	0.50
CaO	43.05
	99.51

INCRUSTATION FROM CASING OF "GRAVEL-BAR GAS-WELL," KISKIMINITAS RIVER, ARMSTRONG COUNTY, PENNSYLVANIA.

[Partial analysis by E. Whitfield.]

Al_2O_3	41.10
SiO_2	50.70
H_2O	3.95
	95.75

Small quantities of iron, magnesia, and organic matter were not determined. The substance is interesting, on account of its mode of occurrence and from the fact that after deducting impurities its composition approximates very closely to the definite silicate, Al_2O_3, 2 SiO_2.

TWO PORCELAIN CLAYS FROM CHINA.

These clays were presented to the United States National Museum by Mr. Arthur B. French, of Boston, who obtained them in person at one of the Chinese potteries at King-te-Ching. They had been prepared for use before reaching the potteries, and were pressed into the form of bricks, each bearing in Chinese characters a stamped impression containing the name of the maker. On account of the absolute authenticity of the material it was thought that analyses might have special value for purposes of comparison with American clays. The sample marked A, of which only a few fragments were obtained, represents material used in the manufacture of the finest white porcelain. Sample B, which has a faint brownish or creamy tinge, was represented by nearly an entire brick, and is the material used in making the so-called "Blue Canton" ware.

[Analyses by E. Whitfield.]

A.

SiO_2	73.55
Al_2O_3	21.09
CaO	2.55
MgO	0.15
H_2O	2.62
	99.96

B.

SiO_2	73.55
Al_2O_3 (contains a little Fe_2O_3)	18.98
CaO	1.58
MgO	1.08
H_2O	1.96
SO_3	0.28
K_2O	0.46
Na_2O	2.09
	99.98

ANCIENT MEXICAN CEMENT.

[From an antique stone floor on the Hill of Texcocingo. Analysis by F. W. Clarke.]

H_2O	7.54
CO_2	18.87
SiO_2	35.56
Al_2O_3, with Fe_2O_3	10.34
CaO	25.41
MgO	2.79
	100.51

Insoluble in HCl, 38.25 per cent. Evidently an ordinary lime-sand cement.

BROWN IRON ORE FROM J. F. C. TALBOTT'S ORE BED, NEAR TIMONIUM, MD.

[Analysis by R. B. Riggs.]

Ignition	12.41
Fe	58.52
Mn	0.34
SiO_2	3.37
S	0.37
P	0.06
Oxygen for Fe and Mn	25.23
	100.30

BROWN IRON ORE FROM D. R. BAKER'S LAND, SHAVER'S MOUNTAIN, RANDOLPH COUNTY, WEST VIRGINIA.

[Analysis by E. Whitfield.]

Fe	47.530
P	0.138
S	0.298
SiO_2	18.930
MnO	0.203

BROWN IRON ORE FROM GOFF AND CRAWFORD'S LAND, ROARING CREEK DISTRICT, RANDOLPH COUNTY, WEST VIRGINIA.

[Analysis by E. Whitfield.]

Fe	39.210
P	0.157
S	0.169
SiO_2	32.790
MnO	0.350

BROWN IRON ORE FROM M'CURRENCE'S LAND, MILL CREEK, RANDOLPH COUNTY, WEST VIRGINIA.

[Analysis by E. Whitfield.]

Fe	44.270
P	0.251
S	0.155
SiO_2	25.400
MnO	0.075

COAL FROM HART'S BANK, RICH MOUNTAIN, RANDOLPH COUNTY, WEST VIRGINIA.

[Analysis by E. Whitfield.]

Water	1.29
Volatile hydrocarbons, &c	31.77
Fixed carbon	62.48
Ash	4.46
	100.00
Sulphur	0.54

Coke, good; ash, pink.

COAL FROM TALBOT'S BANK, ROARING CREEK DISTRICT, RANDOLPH COUNTY, WEST VIRGINIA.

[Analyses by E. Whitfield.]

[A, 3½-foot vein; B, 18-inch vein.]

	A.	B.
Water	0.84	1.14
Volatile hydrocarbons, &c	29.97	31.46
Fixed carbon	60.53	60.71
Ash	8.66	6.69
	100.00	100.00
Sulphur	0.98	1.02

Coke, good; ash, white.

COAL FROM W. H. WILSON'S BANK, NEAR HUTTONSVILLE, RANDOLPH COUNTY, WEST VIRGINIA.

[Analyses by E. Whitfield.]

[A, 13½-foot vein; B, 22-inch vein.]

	A.	B.
Water	0.63	0.77
Volatile hydrocarbons, &c	34.30	34.94
Fixed carbon	55.94	56.96
Ash	9.13	7.33
	100.00	100.00
Sulphur	0.81	1.55

Coke, good; ash, white.

COAL AND LIMESTONE FROM E. T. JONES'S LAND, SHAVER'S MOUNTAIN, RANDOLPH COUNTY, WEST VIRGINIA.

[Analyses by E. Whitfield.]

COAL.

Water	1.54
Volatile hydrocarbons, &c	24.48
Fixed carbon	70.13
Ash	3.85
	100.00
Sulphur	0.54

Coke, fair; ash, pink.

LIMESTONE.

Insoluble	19.87
Fe_2O_3 and Al_2O_3	4.09
CaO	41.29
MgO	.95
CO_2 and H_2O	34.27
	100.47

LIGNITE FROM THE TURTLE MOUNTAINS, DAKOTA.

[Analysis by E. Whitfield.]

Water	13.98
Volatile hydrocarbons	40.81
Fixed carbon	36.90
Ash	8.31
	100.00

COAL FROM ARIZONA.

[Collected by C. D. Walcott in Deer Creek Valley, 13 miles south of the San Carlos Indian Agency. Four samples. Analyses by E. Whitfield.]

	1.	2.	3.	4.
Water	1.59	0.48	3.27	0.56
Volatile hydrocarbons	15.79	19.81	12.51	17.50
Fixed carbon	49.72	61.01	5.72	60.85
Ash	32.90	18.70	78.50	21.09
	100.00	100.00	100.00	100.00

No. 3 was merely shale; Nos. 1 and 2 gave poor coke; No. 4, fair coke; ash, pink, except in No. 3.

WATER FROM MATTHEWS'S WARM SPRINGS, NEAR BOZEMAN, MONT.

[Analysis by R. B. Riggs.]

[Reported temperature of spring, 44°.5 C. Total solids, 0.5925 gramme to the liter.]

Found.		Per cent. of total solids.	Probable combination.	
SiO_2	0.1366	23.05	SiO_2	0.0826
SO_4	0.1335	22.53	Na_2SiO_3	0.1098
CO_3	0.0719	12.13	$CaCO_3$	0.0390
Cl	0.0505	8.52	$MgCO_3$	0.0036
Ca	0 0136	2.30	Na_2CO_3	0.0750
Mg	0.0010	0.16	KCl	0.0134
Na	0.1640	27.69	NaCl	0.0707
K	0.0070	1.18	Na_2SO_4	0.1974
	0.5781	97.56		0.5915
O in SiO_3	0.0134		99.83 per cent. accounted for.	
	0.5915			

The carbonic acid was determined directly. The SiO_3 was computed to satisfy the uncombined base left over after saturating all other acids.

WATER FROM WHITE SULPHUR SPRINGS, MEAGHER COUNTY, MONT.

[Analysis by R. E. Riggs.]

[The water of Spring No. 2 was taken. It contained traces of H_2S. Reported temperature, 45°.5 C. Total solids, 1.551 grammes to the liter.]

Found.		Per cent. of total solids.	Probable combination.	
SiO_2	0.0425	2.74	SiO_2	0.0330
SO_4	0.3025	19.50	Na_2SiO_3	0.0194
CO_3	0.4240	27.34	$CaCO_3$	0.1280
Cl	0.1875	12.09	$MgCO_3$	0.0438
Ca	0.0512	3.30	Na_2CO_3	0.5571
Mg	0.0125	0.79	Kcl	0.0807
K	0.0425	2.74	NaCl	0.2460
Na	0.4900	31.59	Na_2SO_4	0.4463
Li	Trace			1.5543
	1.5527	100.09	100.21 per cent. total.	
O in SiO_3	.0016			
	1.5543			

The SiO_3 was reckoned to saturate the uncombined base left over after satisfying all other acids.

WATER FROM MINERAL SPRING ONE MILE WEST OF SANTA FÉ, NEW MEXICO.

[Analysis by F. W. Clarke.]

[Total solids, 0.2800 gramme to the liter.]

Found.		Per cent. of total solids.	Probable combination.	
SiO_2	0.0220	7.85	SiO_2	0.0220
Ca	0.0634	22.67	$CaCO_3$	0.1538
Mg	0.0173	6.17	$MgCO_3$	0.0605
SO_4	0.0187	6.67	$CaSO_4$	0.0050
Cl	0.0117	4.18	NaCl	0.0193
Na	0.0149	5.32	Na_2SO_4	0.0225
	0.1480			0.2831
CO_3, by difference	0.1320	47.14	101.11 per cent. total.	
	0.2800	100.00		

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DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 28

THE GABBROS AND ASSOCIATED HORNBLENDE ROCKS OCCURRING IN THE NEIGHBORHOOD OF BALTIMORE, MD.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1886

ADVERTISEMENT.

[Bulletin No. 28.]

The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the Library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this Office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Mineral Resources and Dictionary of Altitudes, the Survey has no copies of any of its publications for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth and Sixth Annual Reports are in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, and VIII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt. U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-Lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

ADVERTISEMENT.

The following are in press, viz:

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. ix, 338 pp. 35 pl.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. —, — pp. 56 pl.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl.

XII. Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons.

The following are in preparation, viz.:

I. The Precious Metals, by Clarence King.

— Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

— Lake Bonneville, by G. K. Gilbert.

— Sauropoda, by Prof. O. C. Marsh.

— Stegosauria, by Prof. O. C. Marsh.

— Geology of the Quicksilver Deposits of the Pacific Slope, with atlas, by George F. Becker.

— The Penokee-Gogebic Iron-Bearing Series of North Wisconsin and Michigan, by Roland D. Irving.

— Description of New Fossil Plants from the Dakota Group, by Leo Lesquereux.

— Younger Mesozoic Flora of Virginia, by William M. Fontaine.

— Report on the Denver Coal Basin, by Samuel F. Emmons.

— Report on Ten-Mile Mining District, Colorado, by Samuel F. Emmons.

— Report on Silver Cliff Mining District, by Samuel F. Emmons.

— Flora of the Dakota Group, by J. S. Newberry.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of Annual Reports or Monographs.

Each of these Bulletins will contain but one paper and will be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient sizes. To facilitate this, each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 28 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.
2. Gold and Silver Conversion Tables, giving the coining value of troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price 5 cents.
3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.
4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.
5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.
6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.
7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.
8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.
9. A Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.
10. On the Cambrian Faunas of North America. Preliminary studies, by Charles Doolittle Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.
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[Bulletin No. 28.]

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"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the Library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this Office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Mineral Resources and Dictionary of Altitudes, the Survey has no copies of any of its publications for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth and Sixth Annual Reports are in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, and VIII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt. U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-Lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

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The following are in press, viz:

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. ix, 338 pp. 35 pl.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. —, — pp. 56 pl.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl.

XII. Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons.

The following are in preparation, viz.:

I. The Precious Metals, by Clarence King.

— Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

— Lake Bonneville, by G. K. Gilbert.

— Sauropoda, by Prof. O. C. Marsh.

— Stegosauria, by Prof. O. C. Marsh.

— Geology of the Quicksilver Deposits of the Pacific Slope, with atlas, by George F. Becker.

— The Penokee-Gogebic Iron-Bearing Series of North Wisconsin and Michigan, by Roland D. Irving.

— Description of New Fossil Plants from the Dakota Group, by Leo Lesquereux.

— Younger Mesozoic Flora of Virginia, by William M. Fontaine.

— Report on the Denver Coal Basin, by Samuel F. Emmons.

— Report on Ten-Mile Mining District, Colorado, by Samuel F. Emmons.

— Report on Silver Cliff Mining District, by Samuel F. Emmons.

— Flora of the Dakota Group, by J. S. Newberry.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of Annual Reports or Monographs.

Each of these Bulletins will contain but one paper and will be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient sizes. To facilitate this, each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 28 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining value of troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. A Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

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19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White, M. D. 1885. 8°. 25 pp. 5 pl. Price 5 cents.

23. The Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary fossils and recent forms from American localities between Cape Hatteras and Cape Roque, including the Bermudas, by W. H. Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The Present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 82 pp. Price 10 cents.

26. Copper Smelting, by Henry M. Howe. 1885. 8°. 107 pp. Price 10 cents.

27. Work done in the division of Chemistry and Physics mainly during the fiscal year 1884–'85. 1886. 8°. 80 pp. Price 10 cents.

28. The Gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Md., by George H. Williams. 1886. 8°. 78 pp. Price 10 cents.

Numbers 1 to 6 of the Bulletins form Volume I; Numbers 7 to 14, Volume II; Numbers 15 to 23, Volume III; and Numbers 24 to 30, Volume IV. Volume V is not yet complete.

The following are in press, viz:

29. On the Fresh-water Invertebrates of the North American Jurassic, by Dr. C. A. White.

30. Second contribution to the studies on the Cambrian Faunas of North America, by Charles D. Walcott.

31. A systematic review of our present knowledge of fossil insects, including Myriapods and Arachnids, by Samuel H. Scudder.

32. Report of the Mineral Springs of the United States, by Albert C. Peale.

33. Notes on the Geology of Northern California, by J. S. Diller.

34. On the relation of the Laramie Molluscan Fauna to that of the succeeding Fresh-water Eocene and other groups, by Dr. C. A. White.

35. The Physical Properties of the Iron Carburets, by Carl Barus and Vincent Strouhal.

36. The subsidence of small particles of Insoluble Solid in Liquid, by Carl Barus.

STATISTICAL PAPERS.

A fourth series of publications, having special reference to the mineral resources of the United States, has been undertaken.

Of that series the following have been published, viz:

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1,016 pp. Price 60 cents.

In preparation:

Mineral Resources of the United States for calendar year 1885, by Albert Williams, jr.

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To the Director of the
United States Geological Survey,
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J. W. POWELL, DIRECTOR

THE GABBROS

AND

ASSOCIATED HORNBLENDE ROCKS

OCCURRING IN THE

NEIGHBORHOOD OF BALTIMORE, MD.

BY

GEORGE HUNTINGTON WILLIAMS, Ph. D.
ASSOCIATE PROFESSOR IN THE JOHNS HOPKINS UNIVERSITY.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1886

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NOTE.—These figures were all drawn with the aid of a camera lucida, the aim being to represent some particular spot in a given section as accurately as possible, without attempting to combine the interesting points of several sections or of different portions of the same section.

GABBROS AND ASSOCIATED HORNBLENDE ROCKS.

BY GEORGE H. WILLIAMS.

INTRODUCTION.

Considerable attention has been devoted during late years to the metamorphism of igneous rocks, and it can now be regarded as placed beyond reasonable doubt that such rocks may be changed to more or less schistose masses, which often closely resemble crystallized sediments.[1] This possibility has heretofore been largely ignored, owing doubtless to the extensive obliteration of those characteristics which are generally regarded as most typical of eruptive rocks. Schistose or banded structure, however, can now hardly be considered as necessarily an indication of sedimentary origin. The minerals which are most characteristic of the so-called crystalline schists have been repeatedly shown to be derived from the alteration of igneous as well as of aqueous formations. These minerals only represent the final and most stable combination of certain elements under certain conditions, and are quite independent of the earlier combinations in which these elements may have existed. A lava bed and a clay bank, if the two may be supposed to have originally had the same chemical composition, might, under the influence of the same metamorphic agencies, ultimately give rise to the same rock in spite of original differences in structure or mineralogical composition. Stratification may be obliterated by metamorphism, while foliation, or even a banded structure, may, by the same means, be secondarily induced. Neither structure nor mineral composition can be taken as an infallible guide in determining the origin or the age of rocks.

It would seem but reasonable to suppose that eruptive rocks were more abundant in the early periods of the earth's history than at any time since. The conditions to which such masses have subsequently been subjected, however, must have differed far more widely from those under which they were formed than from those under which sediments were deposited. Might we not, therefore, reasonably expect that igneous rocks would be more readily subject at least to molecular and chemical changes than aqueous formations?

---

[1] Probably the first to study and call especial attention to the metamorphism of eruptive rocks was that admirable and careful geologist, Prof. K. A. Lossen, of Berlin, who, since 1869, has emphasized this point in many papers scattered through the Zeitschrift der deutschen geologischen Gesellschaft, the Sitzungsberichte der Gesellschaft der naturforschenden Freunde zu Berlin, the Jahrbuch der preussischen geologischen Landesanstalt, and through his explanations of various sections of the geological map of the Harz Mountains. His efforts to follow unaltered intrusive rocks in fossiliferous strata into highly dislocated regions, where both they and the sediments have been very much metamorphosed, are deserving of the most careful study. For a full list of his papers on this subject, see Jahrbuch der preuss. geol. Landesanstalt, 1883, p. 619.

The primary cause of regional or, as Lossen calls it, "dislocation" metamorphism is the action of the orographic or mountain-making forces, which in all geological epochs have been upheaving and crumpling one portion or another of the earth's crust. Where the rocks are most disturbed, there they are most changed. The enormous pressure has completely altered their structure, while the increased circulation of heated waters and mineral solutions through the crushed and twisted strata has everywhere facilitated chemical reactions and the formation of new compounds.

The present paper is intended as a contribution to our knowledge of a particular phase of metamorphism in eruptive rocks, i. e., that one which is dependent on the secondary development of hornblende by the paramorphism or pseudomorphism of pyroxene. This is a change the frequency of which renders it of fundamental geological importance. It has already received considerable attention from many eminent geologists, but no locality heretofore studied seems to have afforded opportunities for tracing out every stage in the process of alteration superior to those offered by the area of massive rocks west and northwest of the city of Baltimore. Here, covering a district of over fifty square miles, the unchanged pyroxene rock and its resultant hornblendic equivalent occur in the most intimate relations. Exposures of both rocks in situ are numerous, and the opportunity of following out the gradual transition of one into the other is proportionately great.

Many other localities in this country will doubtless be found to display the same changes on an equal scale, as, indeed, certain observations by Hawes,[1] in New England, and by F. D. Chester,[2] in Delaware, already seem to indicate.

It has not yet been possible for the present writer to study other allied areas in connection with the one near Baltimore. The results already obtained, however, will probably be found to have a widespread application in other regions, and it is in this hope that they are communicated.

This investigation, which, with many interruptions, has extended over a period of nearly two years, was commenced in the fall of 1883 at the Johns Hopkins University, Baltimore, where it has since been carried on. The writer would express his sincere thanks to Dr. Leroy McCay, of the Green School of Science, Princeton, N. J.; to Mr. W. G. Brown, of Charleston, S. C.; and to Mr. W. S. Bayley, of the Johns Hopkins University, for their kindness in furnishing many careful analyses necessary to throw light on some of the most interesting points of the investigation. He is also under obligation to Profs. C. H. Hitchcock, of Hanover, N. H., and F. D. Chester, of Newark, Del., for the loan of thin sections of rocks closely allied to those occurring near Baltimore.

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[1] Mineralogy and Lithology of New Hampshire, 1878, p. 228.

[2] Proceedings Philadelphia Academy of Natural Science, October 14, 1884, p. 244.

SUMMARY.

For the benefit of those to whom the details contained in this paper might not prove of especial interest, as well as to furnish those who purpose to read it with a résumé of its contents, a brief statement of the most important results secured is herewith appended.

Chapter I gives the mode of occurrence and distribution of the rocks investigated. These are principally the dark, trappean-looking masses which occupy an irregularly oval area, nearly fifty square miles in extent, immediately west and northwest of the city of Baltimore. They are externally enough alike to be all included under the local designation of "niggerhead;" but nevertheless, as a closer examination shows, they really comprise three quite distinct types. The first of these is a fine-grained, purplish-black aggregate of hypersthene, diallage, and plagioclase, to which the name *hypersthene-gabbro* is applied; the second is a dark-green rock, composed of fibrous hornblende and plagioclase, which the writer has designated as "*gabbro-diorite;*" while the third is a group of rocks characterized principally by the large amount of olivine which they contain, and on this account to be referred to the family of *peridotites.*

Chapters II and III contain detailed descriptions of the first two of these rock types, their macroscopic appearance, their mode of occurrence, their microscopic structure, and their chemical composition being given at length.

Chapter IV is devoted to the principal point of the paper, viz, the attempt to clearly show that the hypersthene-gabbro and the gabbro-diorite are geologically identical masses, and that the latter has been derived from the former by the secondary alteration of its pyroxene constituents to fibrous hornblende.

§ 1 gives the relations of these two rocks as observed in the field. Wherever they both form part of the same exposure, as may be seen at numerous localities within the area, the one rock always grades imperceptibly into the other; nothing resembling a sharp line of contact is anywhere observable.

§ 2 contains a comparison of the chemical composition of these two rocks. As might be expected from the varying proportions in which the constituents are present in different specimens of the gabbro, chemical analyses of this rock from different localities vary considerably. The results of the chemical examination made of the gabbro-diorite all fall within the limits found in different specimens of the hypersthene-gabbro. In order that a still more satisfactory comparison might be instituted, samples of average composition were obtained in the case of both rocks by powdering together chips of equal size, taken from all the representative specimens of each which had been collected within the entire area. The close agreement between the analyses of these two powders strongly indicates that, in spite of local variations, the two rocks are essentially identical in chemical, if not in mineralogical, composition.

§ 3. The most conclusive evidence in favor of the derivation of the diorite from the gabbro was obtained from the microscopic examination of the zone occurring as a transition between the two rocks. In thin sections from this zone, the pyroxene could be seen in the actual process of alteration to fibrous hornblende. This mineral surrounds the pyroxene in the form of a fringe or border, which gradually increases in width as the diorite is approached, until it finally entirely replaces both diallage and hypersthene. The process of alteration is somewhat different in the case of the two minerals, as might be supposed from the differences in their respective compositions. The diallage may change directly to fibrous green hornblende, as is so often observed in gabbros from all localities. The hypersthene, however, is deficient in both the lime and the alumina necessary to form the hornblende, and appears only to change to this mineral when these constituents are furnished by the adjacent feldspar. This process is quite similar to that observed by Professor Törnebohm in the case of the corresponding unisilicate olivine. The fibrous green hornblende of the gabbro-diorite, which replaces the hypersthene, must, therefore, be regarded as the product of a reaction which has taken place between the substance of this mineral and a plagioclase. This conclusion is substantiated by chemical analyses of all the isolated components of a specimen in which this process of alteration was far advanced.

§ 4 mentions other areas in Europe and America in which changes have been observed similar in character to those here described. It also contains suggestions relative to the conditions and causes necessary to produce uralitization.

Chapter V contains descriptions of the third or olivinitic rock type, which is abundantly associated with the gabbro and gabbro-diorite. These rocks are younger than the gabbro, since they break through it in the form of dikes. They are rarely rich in feldspar and are sometimes altogether free from it. By a gradual loss of olivine they seem also to grade into another massive rock composed almost wholly of diallage and hypersthene. These masses are all very rich in magnesia and readily give rise to the serpentinous hornblendic and talcose rocks which are everywhere abundant in and about the Baltimore gabbro area. As far as could be observed the olivine seems always to form serpentine, and the pyroxene (no matter what be its form), hornblende. This latter mineral often suffers a further alteration to talc, its lime separating out in the form of calcite. In this manner the hornblende serpentines, like those of the Bare Hills, have been derived from original eruptive aggregates of olivine and bronzite, similar in character to many rocks which are still to be found near them in a quite unaltered condition.

CHAPTER I.

THE LIMITS OF THE GABBRO AREA NEAR BALTIMORE AND THE GENERAL CHARACTER OF THE ROCKS COMPOSING IT.

The geological situation of Baltimore is in many respects similar to that of several other of the most important cities on the Atlantic border. Like New York, Philadelphia, Washington, and Richmond, it lies on the wide belt of crystalline strata which follows the coast from Maine to Georgia. How little has thus far been discovered regarding the real age of these rocks, the many rival theories as to their origin but too plainly indicate. At present it seems only possible to regard them, on account of their freedom from all organic remains and their highly crystalline character, as upper members of the pre-Cambrian or Archean formation, although they doubtless include rocks which future study may show to differ widely both in origin and age.

This belt extends from Pennsylvania and Delaware in a south-south-westerly direction across the eastern part of Maryland, into Virginia. The rocks composing it are highly crystalline, for the most part feldspathic, and have a strike which generally conforms to the direction of the belt, though local variations are frequently observed. There is none of the homogeneity or of the granitoid massiveness of the Laurentian formation in Canada or in New York, but on the contrary a finely banded and schistose structure is quite universal. Micaceous, hornblendic, chloritic, and epidotic layers constantly alternate with various kinds of gneiss.

Owing to the absence of glacial action in Maryland, these rocks are almost always more or less decayed to a considerable depth below the surface. This may also be the case even when they appear to the eye quite fresh, as is shown by the rapid disintegration which takes place where apparently unaltered rocks are exposed by railroad cuttings or in quarries. Some bands of gneiss, however, like those quarried on Jones Falls, north of the city line, seem to have resisted the general tendency to decompose, and by their real freshness present a marked contrast to the more altered rocks around them. On account of the readiness with which these gneissoid rocks disintegrate and form soil, blocks or bowlders are but rarely met with on their surface.

The city of Baltimore itself lies on the extreme eastern edge of this crystalline belt, just where it is overlaid by Mesozoic and Tertiary sands, gravels, and clays which everywhere along the eastern shore of the United States compose the strip of territory between the crystalline rocks and the ocean. This covering of sedimentary deposits gradually thins out as the land rises toward the northwest, so that its exact boundary is difficult to trace. Long after the crystalline rocks appear, detached areas of it may be found, occupying levels where it has been sheltered from erosion. The higher and more inland of these unsolidified deposits, like those of New Jersey, Delaware, and Virginia, are to be assigned to the Jurassic-Cretaceous formation. These, in their turn, farther to the east and south, are overlaid by still younger Tertiary deposits. The boundary of both of these divisions is approximately given by Philip T. Tyson on his geological map of Maryland, published in 1860.[1]

The above-mentioned belt of crystalline rocks includes within its limits in Maryland, as in other parts of its extent, many areas of crystalline limestone and serpentine. These are sometimes quite irregular, sometimes lenticular in their shape, and are extensive and numerous enough to form a very considerable proportion of the entire formation.

Huge veins of a coarse-grained pegmatite, which both in their form and in their structure closely resemble intrusive rocks, are also frequently found intersecting the schists and gneisses.[2] As far as my observation extends, the character of these granites seems quite independent of the rock in which they occur. Whether in the lightest, most acidic gneiss or in the darkest hornblende-schist, the coarse-grained aggregate of muscovite, microcline, albite, and quartz appears in all respects the same.

Nor are these rocks — the limestones, the serpentines, and the granites — the only ones which are included in the Archean belt. Massive rocks of a most basic character, and in all probability exotic in their origin, are also occasionally encountered, and it is to the consideration of such an area that the contents of the present paper is devoted.

Immediately west and northwest of the city of Baltimore is situated an irregularly oval district, somewhat over fifty square miles in extent, within which the rocks exhibit a marked contrast to the surrounding gneisses. On his geological map of Maryland, Philip Tyson designated a portion of this area as "trap," an appellation which the character of the rocks here exposed does indeed seem abundantly to warrant.

Wherever along the border of this region the line of contact with the surrounding rocks is not concealed by the overlying Mesozoic deposit, there is a sudden and abrupt transition from the light-colored, well-foliated gneisses and schists to heavy, black, massive rocks in which a schistose structure is exceptional and, when present at all, mostly confined to the periphery of the mass. Perhaps, however, the most striking contrast is presented by the resistance offered by these dark rocks to the action of atmospheric influences. Instead of readily disintegrating like the gneiss, they break up, in consequence of their jointed structure, into huge polygonal blocks which strew the surface of the ground in countless numbers wherever they have not been carefully removed by the farmers.

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[1] First annual report of P. T. Tyson, State agricultural chemist, to the house of delegates of Maryland. 1860.

[2] Johns Hopkins University Circulars, No. 38, p. 65. March, 1885.

The entire area is characterized by the substitution of black stone walls for the usual rail fences.

The large blocks, which, on account of their color, weight, and hardness, are locally known as "niggerheads" or "ironstone," are sometimes rounded, but generally angular in shape. In some exposures of the rocks, where the blocks have never been removed from their original position, complete decomposition to a deep-red, clay-like substance may be seen to have taken place along the cracks and fissures formed by jointing, although at a distance of less than a quarter of an inch from this material the rock retains its original freshness. When first taken from the ground the blocks of this rock are generally covered with a coating of this same decomposition product, which, however, is soon washed away by rain, leaving the natural color exposed.

The deep-red color of the soil in some portions of the area occupied by these rocks seems to be due to this decomposition, although in other localities, on account of variations in composition—to which, as we shall see further on, these rocks are especially subject—the same alteration produces a soil of a light buff color.

The contact between these dark rocks and the surrounding gneisses is rarely well exposed; even where it is concealed, however, the limits of the area may, in most cases, be quite accurately determined either by the sudden change in the color of the soil or by the number of angular blocks which at once appear as soon as the "niggerhead" region is entered. This, of course, is not true where the overlying covering of Mesozoic sand and gravel buries the contact far below the surface, as is the case in the southern portion of the region.

Where the contact between "niggerhead" and gneiss is exposed, as in the railroad cutting south of Melvale on the Northern Central Railroad or in that on the Western Maryland Railroad near Highland Park, it is rarely a sharp line. As a rule the two rocks alternate with each other for some little distance, as though dikes of the darker rock had penetrated the gneiss around the border of the main mass.

North of the Franklin road, which runs out of the city toward the west, the boundary of the area in question has been located with considerable accuracy, and is given upon the accompanying map[1] (Plate IV). Starting just north of Calverton Heights it runs in a northeasterly direction, crossing the Western Maryland Railroad south of Highland Park Station. It passes a short distance northward of Druid Hill Park to the village of Woodberry, where a tongue of it crosses Jones Falls. Returning to the west side of the Falls between Woodberry and Melvale, the boundary extends in a sinuous line as far north as Mount Washington. Here it turns quite abruptly to the west, following very closely the direction of Smith's avenue as far as Pikesville. Beyond Pikesville the line bends slightly toward the south until it reaches a point about one mile east of Randallstown, where it takes a southward course, crossing the Patapsco River a short distance north of Hollofields Station. It soon, however, recrosses the river, but returns again farther south and sends a narrow belt for a considerable distance westward into Howard County. South of this point the limits of the area cannot be traced with any accuracy, owing to the rapidly-increasing thickness of the Mesozoic deposits. A few exposures of the black rock may be seen at North Bend, on the Frederick turnpike, on the new road leading from Orange Grove to Catonsville, and at several points on the Baltimore and Ohio Railroad in the Patapsco Valley. In the latter case, however, it is only found at a few places imbedded in the prevailing gneisses and schists, so as to resemble tongues or dikes, which stretch southward beyond the southern limits of the main mass.

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[1] The map upon which the limits of the areas occupied by the "niggerhead" and serpentines near Baltimore are traced, is a portion of the more extensive one recently compiled and edited by Mr. Albert L. Webster, at the request of the trustees of the Johns Hopkins University. This map, which covers an area 25 miles square, with the city hall of Baltimore as its center, was intended primarily for the use of the University Naturalists' Field Club. It has already rendered valuable service, although, being merely a compilation from existing materials, it contains many errors and no topography.

The relations of several areas of black but schistose rocks, lying outside of the region whose limits have here been traced, will be mentioned beyond.[1]

At any characteristic exposure within the limits of the area above outlined, it takes but a superficial examination to detect the presence of two rocks, mineralogically altogether distinct, although they are everywhere so intimately associated as to be geologically inseparable.

Both rocks are so heavy, dark, and massive as to be included under the local designation of "niggerhead," but the purplish tinge of one is alone sufficient to distinguish it from the dark-green color of the other. A closer examination with the aid of a pocket lens discloses the fact that the purplish-black rock is composed of a glistening, striated feldspar and pyroxene, the latter constituent being almost always present in two readily distinguishable forms, diallage and hypersthene. The greenish-black rock, on the other hand, which is much the commoner of the two, is made up of the same feldspar and a green hornblende with a satiny luster.

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[1] A compact, massive rock, which, from its mode of occurrence or from a macroscopical examination, cannot be distinguished from the typical rock of the "niggerhead" area, is found in the gneiss, at a point near McDonogh, some distance north of Pikesville, and so outside of the limits above outlined (No. 180). It is interesting to note, however, that the microscope shows this rock to be altogether different from the other, having nothing, as regards either structure or mineralogical composition, in common with it. The McDonogh rock agrees in all respects with the normal Mesozoic diabase of the Atlantic border, with which, as we shall see, the Baltimore "niggerhead" has nothing to do.

On account of the purely granular structure of the first rock, as well as on account of the physical properties of its two pyroxenic components, it must, in accordance with the most generally accepted rules of petrographical nomenclature, be designated as a *hypersthene-gabbro.* The second, greenish rock, in consideration of its close association with the first rock and probable derivation from it, we may call a *gabbro-diorite.*[1]

As has already been stated, these two rocks are everywhere so intimately associated that no geological separation of them is possible; nevertheless they are mineralogically altogether distinct. It will therefore be expedient to give a somewhat detailed description of the two types in their most characteristic forms, based upon the microscopic study of a large number of thin sections prepared from specimens collected at all accessible localities. Afterward the mutual relations of these two rocks will be discussed from a geological, chemical, and petrographical standpoint, and finally the general conclusions derived from such a discussion will be stated.

Another class of basic, massive rocks may be here mentioned as occurring in and around the gabbro area, although it is, both geologically and mineralogically, quite distinct from the one just described. Small dikes and lenses of a dark-brown rock are frequently encountered which apparently intersect the gabbro and gabbro-diorite, and are hence younger than these. This rock is composed of olivine, diallage, and bronzite, with varying quantities of a basic, triclinic feldspar. When the latter constituent is abundant the rock must be designated as an *olivine-gabbro,* but the small amount of this mineral commonly present would consign it, with almost an equal right, to the family of the *peridotites.*

. Resulting from the undoubted alteration of these rocks are certain others containing hornblende or serpentine, which are in all respects identical with still other masses in which no trace of the original minerals is longer to be found. These olivine rocks, with their associates and derivatives, are considered in the final chapter.

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[1] This name is assigned in accordance with the usage of Prof. A. E. Törnebohm, of Sweden (Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, 1877, p. 391), as being the one which conveys the most information regarding both the mineralogical composition and the origin of the rock in question. In their most typical development these rocks are diorites, except that the hornblende is more than usually satiny and fibrous. Many of them resemble the "*Epidiorit*" of Gümbel, from Belgium and Bàvaria. In a preliminary notice of the Baltimore gabbros (Johns Hopkins University Circulars, No. 30, April, 1884), they were called by the present writer *anorthite-amphibolites,* in accordance with the usage of some German authors. Similar rocks have also been designated in Germany as "*Diorit,*" "*Dioritschiefer,*" "*Amphibolschiefer,*" &c. In this country they were called by Dr. G. W. Hawes "*metamorphic diorites.*" Zirkel early suggested calling all anorthite-hornblende rocks "*corsite,*" but in this he does not appear to have been generally followed. The name gabbro-diorite was also independently employed by Maj. T. B. Brooks in 1879 (Geol. of Wis., Vol. III, p. 522).

CHAPTER II.

PETROGRAPHICAL DESCRIPTION OF THE HYPERSTHENE-GABBRO.

The first-mentioned purplish-black rock of the Baltimore "niggerhead" area, on account of its granular structure and mineral components, can only be classified as a gabbro. It nevertheless possesses a compactness of texture, a fineness of grain, and a freshness which are very exceptional in rocks generally considered as most typical of this family. It furthermore gains an additional interest from the large amount of hypersthene which it contains, inasmuch as the presence of this constituent makes it a connecting link between the true gabbros and the norites.

The number of localities within the United States where gabbros are thus far known to occur is quite small, although this is undoubtedly due rather to the fact that these rocks have not yet been recognized than to their really limited distribution. In the year 1876, Zirkel described the first American gabbro from Iron Mountain, Laramie Hills, Wyoming.[1] During the following year, Streng made known the hornblende-gabbros occurring on the St. Louis River, Minnesota,[2] and in 1878 appeared Dr. George W. Hawes's account of the gabbros of New Hampshire.[3] Still more recently Prof. R. D. Irving has studied the gabbros occupying enormous areas in Wisconsin, Michigan, and Minnesota.[4] In these rocks hypersthene was not observed except in one instance, at Waterville, N. H.[5]

The presence of this mineral in such abundance in the Baltimore rock renders its relation at once apparent to the hypersthene rocks occurring near Peekskill, N. Y., called by H. Credner "hypersthenite,"[6] and by Prof. J. D. Dana norite.[7] Numerous unpublished observations made on sections of similar rocks from many localities in Pennsylvania and Delaware seem to indicate a hitherto unsuspected distribution of this mineral in the so-called "traps" of the Archean formation. This fact is especially interesting when considered with reference to the coarser-grained masses of the Norian system in New York and Canada, in which hypersthene has long been known to be an almost universal constituent.

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[1] Microscopical Petrography, Washington, 1876, p. 107.

[2] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, pp. 113–117. 1877.

[3] Mineralogy and Lithology of New Hampshire, 1878, pp. 165–173.

[4] Geology of Wisconsin, Vol. III, p. 168, 1880. Copper-Bearing Rocks of Lake Superior, Monographs of the United States Geological Survey, Vol. V, pp. 37–57.

[5] Mineralogy and Lithology of New Hampshire, 1878, p. 54.

[6] Zeitschrift der deutschen geologischen Gesellschaft, XVII., p. 390. 1865.

[7] American Journal of Science (III), XX, p. 194, Sept., 1880.

In Europe gabbros are very common rocks, while even those which contain an orthorhombic pyroxene are not rare. They are known among other localities, in Saxony, Silesia, the Harz Mountains, and Scandinavia. There are many points of resemblance between the Baltimore gabbro and the "*Trapgranulit*" of Saxony, although the American rock is free from garnet.[1]

Professor Törnebohm has proposed to restrict the old and much-abused name "*Hyperite*" to certain gabbros which contain hypersthene.[2] His descriptions indicate a close similarity between the Swedish and Baltimore rocks.[3]

Excellent exposures of the hypersthene-gabbro are very abundant within the Baltimore area, especially in the northern portion of it. Among the localities where this rock may be seen to advantage in position may be mentioned the Western Maryland Railroad between Oakland Station and Howardville; the region around Franklin, Powhatan Mills, and Wetheredville, and west of these places on the old Liberty and Windsor Mill turnpikes; in Gwynn's Falls, north of the Windsor road bridge; in Jones Falls, north of Woodberry; along the road leading northward from Ellicott City, in Howard County. Perhaps the best place to obtain fresh and typical specimens is at Mount Hope Station, on the Western Maryland Railroad, although they may be secured from the huge bowlders which strew the surface at almost any spot within the area.

This rock is always very massive in appearance, rarely exhibiting the banded and nowhere the schistose structure which is frequently seen in the associated hornblendic rocks. Its irregular polygonal blocks are often covered with a thin coating of a deep red color due to decomposition, beneath which, however, as has already been mentioned, the rock is surprisingly fresh.

The mineral constituents of the gabbro which are discernible with the unaided eye are plagioclase, diallage, and hypersthene. A black hornblende, which is brown in transmitted light, is also sometimes seen in good-sized crystals and has every appearance of being a primary component. Magnetite and apatite are shown by the microscope to be universally present, although in varying quantities. Olivine was observed in only one specimen, collected near Orange Grove. With the exception of certain indeterminable inclusions no other minerals were discovered in the wholly unaltered rock. (Plate I, Fig. 1.)

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[1] This resemblance is even much closer in the case of certain rocks occurring at Claymont, Del., which are much like those at Baltimore. Here the garnet is present, as in the Saxon rocks.

[2] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 379. 1877.

[3] Still closer is the resemblance to the hypersthene-gabbro from Ekersund, in Norway, recently described by Prof. H. Rosenbusch (Nyt Magazin for Naturvideskaberne, XXII, pp. 304-309, 1882).

The grain of the hypersthene-gabbro is, as a rule, uniform and fine, the component minerals averaging from one to two millimeters in diameter. Exceptionally, however, the grain becomes coarser; in a few specimens the individuals of pyroxene and feldspar measured from twenty-five to thirty-five millimeters in length. The coarsest varieties are rarely altogether fresh.

The feldspathic constituent of the hypersthene-gabbro is *bytownite*, corresponding to a mixture of six molecules of anorthite with one of albite. A comparative study of this mineral in many different specimens of the rock showed the greatest constancy in its composition and physical properties. Stauroscopic measurements on the feldspar extracted from a Mount Hope specimen of the gabbro (No. 56)[1] gave extinction angles (measured against the cleavage lines) of — 16° to — 19° on OP (001) and of — 28° to — 30° on ∞ P ∞̆ (010).

	I.	II.	III.
SiO_2	46.17	48.94	46.5
Al_2O_3	35.23	33.26	34.6
CaO	16.29	15.20	17.3
Na_2O	[a]2.31	3.30	1.6
Total	100.00	100.70	100.0

[a] Difference.

In the above table of analyses, I is of the pure feldspar powder extracted from the Mount Hope specimen. It was made by Mr. W. S. Bayley in the chemical laboratory of the Johns Hopkins University. II is an analysis by Ludwig of what Tschermak regards as a typical bytownite from Närödal in Norway.[2] III is the theoretical composition, calculated by Schuster, for a mixture of six anorthite molecules with one of albite.[3]

The specific gravity of the powder used in analysis I was determined by means of the Thoulet solution to be 2.74, which agrees very well with the results of the optical and chemical investigations.

In the above-mentioned specimen of gabbro from Mount Hope the feldspar constitutes somewhat over one-half of the entire mass. This may perhaps be regarded as a fair average, although great variations in the proportions of the component minerals cause the analyses of specimens of the gabbro from different localities to differ widely, as will be shown in the sequel.

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[1] The numbers given with the succeeding descriptions are those attached to specimens in the Johns Hopkins University collection.

[2] Sitzungsberichte der k. Akademie der Wissenschaften. Bd. L. Wien, 1 Juli 1869.

[3] Mineralogische und petrographische Mittheilungen, III., p. 153. 1881.

The feldspar individuals are generally quite irregular in shape, giving rise to the granular structure which is characteristic of gabbro in contrast to diabase. Rarely, however, a lath-shaped crystal indicates a slight tendency toward the ophitic structure.

When seen between crossed nicols, the feldspar appears, as a rule, finely striated. Sometimes two systems of striæ are seen to intersect at an angle of nearly 90°. In other cases the striations are very coarse or altogether wanting, in which case the extinction is more or less undulatory and irregular.

The minute, dust-like inclusions, which are so common in the feldspars of the older basic rocks, are admirably developed in the Baltimore gabbros. They answer very well to the descriptions given of them in rocks from other localities by Zirkel, Hagge, Hawes, and other investigators. When viewed with a low magnifying power the plagioclase appears to be covered with a fine black or brown dust, which, under the highest magnifying power, is resolved into a mass of very minute opaque dots and lines. The arrangement of these inclusions is such that the needles occupy the center of the crystal; this is surrounded by a zone where only the dots or globulites are to be seen. The exterior of the crystal is generally free from inclusions of any kind. Frequently the acicular bodies are altogether absent and then the minute dots are arranged in lines which indicate the position of the twinning lamellæ. An occasional inclusion of another kind, like a fluid cavity, an apatite crystal, or a grain of magnetite, is surrounded by a narrow zone which is quite free from the dust-like particles. (See Plate I, Fig. 1.) Neither a microscopical nor a chemical examination served to give any clew to the mineralogical nature of these minute bodies.

The diallage is the constituent of the gabbro next in order of importance to the feldspar, although in some specimens it is not so abundant as the hypersthene. A chemical analysis of this mineral, isolated by means of the Klein solution, from a Gwynn's Falls specimen (No. 148), was made by Mr. W. G. Brown, lately of the University of Virginia, with the following result:

SiO_2	51.414
Al_2O_3	4.323
FeO	9.307
MnO	0.043
CaO	20.600
MgO	15.138
	100.825

The specific gravity as determined by the Klein solution is 3.26.

In hand specimens the diallage appears black, but when seen by transmitted light in thin sections it has a light-green color and exhibits no appreciable pleochroism. This constituent, like all the others, shows no indication of a crystal form; it is present only in rounded or irregularly-shaped grains, and appears to have crystallized somewhat later than the feldspar. The prismatic cleavage and the parting parallel to the orthopinacoid are both well developed; frequently a second parting parallel to the clinopinacoid is also present. In sections approximately parallel to either OP (001) or $\infty P \bar{\infty}$ (100) an optical axis—not a bisectrix—appears, when the examination is made with converged polarized light. Clinopinacoidal sections exhibit an extinction angle as large as 40°.

Twins, according to the ordinary law for augite, where the orthopinacoid is both twinning plane and composition face, are quite common. Instances where the twinning trace is inclined from 25° to 35° to the cleavage lines, as described by Cohen,[1] Rosenbusch,[2] and others, have been also not infrequently observed. The explanation of these twins recently suggested by Mr. George F. Becker[3] does not appear to be applicable in the case of the Baltimore gabbros, inasmuch as the extinction for both portions of the crystal is nearly simultaneous. It can be seen that this could not be so if the section were really one of an ordinary twin cut parallel to a very acute pyramidal face.

Other systems of fine striations, visible only between crossed nicols, are very often seen traversing the individuals of diallage in several directions. They are by no means always straight in their course nor continuous across the crystal, but appear to be due to some molecular disturbance produced by pressure, to which, as is well known, this mineral is peculiarly sensitive.[4]

In its freedom from inclusions the diallage, as a rule, presents a contrast to the hypersthene, although when such inclusions are exceptionally present they do not appear materially to differ from those of the rhombic pyroxene.

Hypersthene is a constant component of the Baltimore gabbros, although its amount varies widely in different specimens. It is readily detected in the rock by its bronzy luster, and may be often seen spangling a section with metallic-looking spots even before it is brought under the microscope. This effect is, however, altogether due to inclusions in the hypersthene; and, since these may be wanting, the absence of the metallic reflection is of itself no proof that this mineral is not present.

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[1] Geognostische Beschreibung der Umgegend von Heidelberg, p. 69. 1881. Sammlung von Mikrophotographien, etc., Taf. XXVIII., Fig. 4. 1881.

[2] Mikroskopische Physiographie. Vol. II. Die massigen Gesteine, p. 410. 1877.

[3] Geology of the Comstock Lode, Monographs of the United States Geological Survey, Vol. III, 1883, p. 113, Pl. IV, Fig. 28. See, also, the elaborate explanation of these apparently anomalous twins given by F. Becke in the Mineralogische und petrographische Mittheilungen, VII. Bd., p. 98. 1885. This explanation is essentially the same as that of Becker.

[4] Van Werveke: Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, II., p. 97. 1883.

A chemical analysis of this hypersthene, which was isolated from the above-mentioned specimen (No. 148), yielded Mr. Brown the following results:

SiO_2	52.12
Al_2O_3	1.69
FeO	20.94
CaO	3.20
MgO	21.56
Total	99.51

The specific gravity of the powder analyzed was 3.35.

Under the microscope this mineral exhibits no better crystalline form than the diallage, from which, however, it is easily distinguished by its marked trichroism. The ray which vibrates parallel to the brachydiagonal axis ($\breve{a} = \mathfrak{a}$) is brownish-red; the one vibrating parallel to the macrodiagonal ($\bar{b} = \mathfrak{b}$) is light greenish-yellow, while that one which vibrates parallel to the vertical axis ($\dot{c} = \mathfrak{c}$) is green. The absorption is $\mathfrak{a} < \mathfrak{c} < \mathfrak{b}$, $\mathfrak{c}$ being very nearly equal to $\mathfrak{a}$. This agrees with the results of F. Becke's examination of the hypersthene from Bodenmais, in Bavaria,[1] although Haidinger, Tschermak, Rosenbusch, Fouqué, and other authors give the absorption of this mineral as $\mathfrak{c} < \mathfrak{a} < \mathfrak{b}$.

The cleavage parallel to the unit-prism ∞P (110) is well developed; but even more pronounced is a parting parallel to both pinacoids $\infty P \breve{\infty}$ (100) $\infty P \bar{\infty}$ (010), which renders it possible to readily place the orthorhombic character of the mineral beyond a doubt.[2] If the isolated hypersthene powder be brought under the miscroscope, numerous cleavage pieces parallel to the orthopinacoid (recognized by their green and yellow dichroism) are observed, which, in converged polarized light, show a bisectrix with both axes in the field. Basal sections also show a bisectrix in converged light. All sections in the prismatic zone show in parallel polarized light an extinction parallel to the cleavage lines, which, together with the above-mentioned interference figures, is abundant optical proof that the mineral is really orthorhombic and not a pleochroic diallage. The fact that the brachydiagonal axis is the acute bisectrix and the optical angle comparatively small is sufficient indication that it is hypersthene, and not enstatite or bronzite, with which we have to deal.

The peculiar inclusions so generally characteristic of hypersthene are, as a rule, present in great perfection. They have been so often described that no extended notice of them is here necessary, especially as nothing new regarding their arrangement or nature can be added to what has already been stated by Kosmann[3] and Hagge.[4] Suffice it to say that they were found to be in all respects identical with the inclusions in the well-known hypersthene (paulite) from the coast of Labrador. They are composed of fine needles arranged parallel to all three crystallographic axes and of little plates of a reddish-brown color lying parallel to the brachypinacoid. To these latter the peculiar metallic reflection seen in many sections is due. They vary considerably in thickness, as may be seen by the different depths of color which they possess. These plates all extinguish simultaneously with the hypersthene, which may be due to their extreme thinness or to the fact that they have their axes parallel to those of their host. Kosmann was inclined to regard these inclusions as brookite. Although generally abundant,[1] they are sometimes entirely absent from the hypersthene.[2]

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[1] Mineralogische und petrographische Mittheilungen, III., p. 65. 1880.

[2] H. Rosenbusch: Gesteinsarten von Ekersund. Nyt Magazin for Naturvideskaberne, XXII, p. 305. 1882.

[3] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 532. 1869.

[4] Mikroskopische Untersuchungen über Gabbro- und verwandte Gesteine. Inaug. Dis., p. 10. Kiel, 1871.

A yellowish-brown hornblende, undoubtedly of primary character, is sometimes met with in the hypersthene-gabbro. Such a constituent is mentioned by many writers as an accessory in gabbros from other localities. In this way a series of rocks is formed which is related to the normal gabbros in the same manner as the "proterobase" of Gümbel is related to the normal diabase. This primary hornblende is, in the Baltimore gabbros, strongly pleochroic. The $\mathfrak{a}$ ray, approximately parallel to the clinodiagonal axis, is light-yellow; the $\mathfrak{b}$ ray, coinciding with the axis of symmetry, is brownish-yellow; while the $\mathfrak{c}$ ray, inclined about 12° to the vertical axis, is yellowish-brown. The absorption is, as usual in hornblende, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$ or $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$.

This hornblende is sometimes so full of minute black inclusions as to be nearly opaque, even when in very thin sections. These interpositions are, however, not evenly distributed, but are massed in irregular patches. No trace of external crystalline form is ever discernible. This mineral appears to have been the last to crystallize from the magma, a single individual often covering a considerable space and inclosing smaller grains of both pyroxene and feldspar. It is not infrequently intergrown with pyroxene in such a manner that the orthopinacoids of both minerals are coincident. On the whole this hornblende appears to be in all respects identical with that occurring so plentifully in the augitic and hypersthenic rocks of Dana's "Cortlandt series" near Peekskill, N. Y.

The occurrence of this hornblende in the least altered specimens of the gabbro, its compact structure, and the other marked contrasts which it presents to the green, fibrous amphibole to be hereafter described are all a sufficient warrant for its original character.

Of the other constituents occurring in the hypersthene-gabbro, the magnetite and the apatite present no peculiarities worthy of mention. The former is never very abundant, the latter rarely so, although in one specimen (No. 56) from Mount Hope, it was found to compose 12 per cent. of the entire mass of the rock.

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[1] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 501. 1871.

[2] Regarding the original nature of these and similar inclusions, so generally found in the constituents of the older massive rocks, the writer has expressed his views in the American Journal of Science, XXXI (3), p. 33, January, 1886.

Olivine was detected in only one specimen (No. 69), found near Orange Grove Station, on the Baltimore and Ohio Railroad.[1] Here it was only sparingly present in small, irregular grains, which, however, were remarkably fresh. Wherever it is in contact with the feldspar, the olivine is surrounded by the peculiar border of fibrous amphibole, first described by Törnebohm and attributed by him to a reaction between the substance of the two minerals.[2]

Accidental minerals are rare in the Baltimore gabbros. At some localities vein-quartz—evidently a secondary infiltration into existing cracks and fissures—is abundant. Long crystals of black tourmaline, forming radiating groups sometimes two feet in diameter, are found imbedded in this quartz at Gwynn's Falls, near the Windsor road bridge, and near Wetheredville; also, in Jones Falls, a short distance north of Woodberry.

Associated with this quartz, west of Mount Hope Station and along Gwynn's Falls, north of the Liberty road, are many blocks of a coarse-grained muscovite granite or pegmatite, which is to all appearances identical with that occurring so abundantly in the gneisses. (Johns Hopkins University Circulars, No. 38, page 65, March, 1885.) This rock is composed of a flesh-colored microcline, white albite, quartz, and muscovite; garnet and tourmaline are also not rare constituents. The occurrence of this pegmatite, so rich in alkalies, in the center of the gabbro area may be regarded as a fact in favor of its exotic nature so far as it shows that this rock is not dependent upon the nature of the inclosing mass, as might naturally be expected to be the case with segregation veins.

The most striking feature in the texture of the unaltered gabbro is the repeated and abrupt change in the coarseness of the grain which is seen at some localities. This phenomenon, as is well known, is one frequently observed in very ancient massive rocks which cover considerable areas. It was undoubtedly caused by some irregularity in the cooling of the original magma from a molten state, for which it is now difficult to find a satisfactory explanation.

The coarsest-grained varieties of the Baltimore gabbro occur in the neighborhood of Wetheredville, and there these sudden changes in texture are most apparent. Irregular patches of the coarsest kinds lie imbedded in those of the finest grain, without regard to any order. In other cases, a more or less pronounced banded structure is produced by an alternation of layers of different grain or by such as have one constituent developed more abundantly than the others. Such bands are not, however, parallel, but vary considerably in direction and show a tendency to merge into one another, as though they had been produced by a motion in a liquid or plastic mass.

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[1] The percentage of silica (44–46 per cent.) in these Baltimore rocks is so low for a normal gabbro that the absence of olivine is striking. Possibly the place of this mineral is here supplied by the corresponding bisilicate hypersthene, as has been shown by Hague and Iddings to be the case with many of the basalts when they become slightly more acidic. (American Journal of Science (3), XXVI, p. 244. September, 1883.)

[2] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 383. 1877. See, also, F. D. Adams: American Naturalist, November, 1885, p. 1087; and the writer: American Journal of Science, January, 1886, p. 35.

One peculiar structure was observed in a huge block of gabbro discovered in Jones Falls, near Woodberry (No. 156). The main body of the rock, which was entirely massive, was composed of a grayish gabbro, in which were numerous dark-brown, lenticular patches, some two inches in length, arranged with their longest axes parallel in direction. This remarkable mottled appearance was due, as the microscope showed, to the replacement, in the darker colored spots, of the pyroxene of the gabbro by the primary brown hornblende above described.

The color of the hypersthene-gabbro is on the whole uniform, although it may vary from a purplish-black to gray. The latter varieties show an almost entire absence of the inclusions from the pyroxene constituents and produce by their decomposition a light-buff instead of the more common dark-red soil.

Chemical analyses of the hypersthene-gabbro are given and discussed in connection with those of the gabbro-diorite, in Chapter IV, section 2, p. 37.

CHAPTER III.

PETROGRAPHICAL DESCRIPTION OF THE GABBRO-DIORITE.

The very intimate association of the hypersthene-gabbro near Baltimore with a greenish, more or less schistose rock, to which the name gabbro-diorite has been applied, has already (p. 17) been mentioned. In its typical development, this rock may readily be distinguished from the gabbro, so that it will be advantageous to describe it in some detail before considering the relations of the two rocks to each other. As regards their distribution the diorite is much the commoner, for, whereas it frequently occurs over considerable areas alone, the gabbro is always accompanied by the hornblende rock.

In typical specimens the color alone is enough to distinguish the gabbro from the diorite; intermediate varieties, however, often occur, which cannot by this means be certainly identified.

A closer examination of the diorite shows it to be composed of a fibrous, green hornblende, possessing a satiny luster, and an opaque white feldspar, which, on account of its altered condition, is more prominent in this rock than in the gabbro. In blocks which have been long exposed this feldspar is often completely weathered out on the surface, giving the rock a peculiarly pitted appearance.

Frequently the diorite is not less massive than the gabbro; but in other cases it exhibits a pronounced schistose structure, which, as far as observed, is conformable with the foliation of the adjacent gneisses. The same direction is often indicated by the arrangement of the rock constituents, even where no proper foliation is present. The hornblende is interspersed with long dashes of feldspar, which follow the general direction of the lamination. In other cases the two principal constituents are disposed in parallel bands.

Other minerals than the feldspar and amphibole are rarely visible to the unaided eye. Occasional grains of pyrite and crystals of red garnet[1] are almost the only exceptions. The microscope disclosed in addition epidote, apatite, magnetite, and rarely rutile and sphene.

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[1] This mineral was observed in exceedingly sharp dodecahedral crystals, often measuring several millimeters in diameter, in the diorite near the center of the long railroad cutting at Mount Hope.

The hornblende is the usual green variety common in massive diorite and crystalline schists. It almost never occurs in well-defined crystals, but in confused aggregates of imperfectly developed individuals. The extinction angle, measured, as proposed by F. Becke,[1] on splinters parallel to the prismatic cleavage plane, gave an average value of about 13°. The pleochroism is very pronounced and of the character usual in hornblende, i. e., the $\mathfrak{a}$ ray, nearly parallel to the clinodiagonal axis, is light-yellow; the $\mathfrak{b}$ ray, coincident with the orthodiagonal, yellowish-green; and the $\mathfrak{c}$ ray, dark bluish-green. The absorption is here as in all hornblende $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

As has already been mentioned, the green hornblende of the diorite is rarely present in compact individuals of any size. As a rule many minute crystals are crowded together in a confused aggregate, giving rise to the characteristic satiny appearance which this mineral possesses in hand specimens. In some cases this subdivision is carried so far that even the microscope is unable to resolve the hornblende into its ultimate components. This, which is a truly fibrous hornblende or uralite, is composed of the finest possible needles, whose axes are only approximately parallel, so that between crossed nicols the crystal can never become at one time perfectly dark. (No. 12, collected north of Druid Hill Park.)

Another curious and interesting structure is occasionally encountered in the hornblende of this rock. Each individual is externally quite homogeneous and compact, but internally is composed of an irregular mixture of hornblende needles and quartz grains. The former generally have their crystallographic axes nearly parallel, although they may have an altogether different orientation from the external hornblende rim. The rim itself may also differ in its optical orientation at different points.[2] (See Plate III, Fig. 1.)

No other occurrence of quartz was observed as a true constituent of the gabbro-diorite.[3]

The specimens which exhibited this remarkable structure to the best advantage were found in the Western Maryland Railroad cutting at

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[1] Mineralogische und petrographische Mittheilungen, IV., p. 235. 1882.

[2] Exactly this same structure was seen in a rock, called by Professor Törnebohm "hyperite-diorite," from Ölme, in Sweden. This investigator regards it as undoubtedly due to the alteration of the pyroxene constituent of a hyperite or gabbro which is found in considerable quantity associated with it. This rock is represented by slide No. 21, in the collection of Swedish rock sections prepared by R. Fuess, of Berlin. It is described in the Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 385, 1877, by Törnebohm, who mentions that it also contains garnet, like its American equivalent.

[3] Large veins of quartz are even commoner in this rock than in the gabbro. At Mount Hope these are especially well developed. The hornblende seems to be massed in a black rim at their edge, and frequently large, well-defined crystals of this mineral lie wholly imbedded in the quartz. Black tourmaline and pyrrhotite occur in the same connection.

Mount Hope (Nos. 92, 93, and 103*b*). They contained small but sharp dodecahedrons of red garnet.

The ordinary hornblende of the diorite is quite free from inclusions, but in certain specimens crystals much larger and more compact than the average occur, in which minute black needles are so abundant as to render the mineral quite opaque, no matter how thin the section may be. These needles are short and stout, being often so rounded as to present an elliptical outline. They vary considerably in size, but even the largest are not more than $\frac{1}{25}^{mm}$ in length and $\frac{1}{500}^{mm}$ in width. In prismatic sections of the hornblende they are seen to be arranged parallel to the vertical axis, and also in two directions, making an angle of about 45° with this. In basal sections they appear to follow for the most part the prismatic cleavage lines, though they are also less frequently disposed in other directions, especially in that parallel to the clinodiagonal axis.

These inclusions furthermore are always central in their arrangement, the periphery of the hornblende crystal being free from them. When particularly abundant, the smaller needles appear to run together, forming irregular, opaque masses, much resembling magnetite. That these inclusions are in reality magnetite is indicated by the fact that such crystals of hornblende as contain them most abundantly are attracted by the magnet while others are not.

Both the compact structure and the inclusions of this green hornblende are points of close resemblance to the brown variety of this mineral mentioned in connection with the hypersthene-gabbro. Whether that here described is a primary or a secondary product it is difficult to say, although all appearances indicate the former supposition as the more probable. It seems as though the compact green variety might represent the primary brown hornblende of the gabbro, which has undergone no other change than that of its color.

Specimens showing this mineral to the best advantage were collected near Mount Hope. (Nos. 95, 96, and 110.)

The feldspar of the diorite is identical with that of the gabbro. For examination this component was separated from a very typical diorite specimen from the neighborhood of Pikesville (No. 64). Stauroscopic measurements under the microscope were not altogether satisfactory on account of the very minute size of the grains. A large number of trials made upon this isolated powder gave upon such particles as showed twinning lamellæ—i. e., those parallel to OP (001)—values varying from 22° to 28°, while upon those without lamellæ—i. e., those parallel to $\infty P \breve{\infty}$ (010)—extinction angles as high as 36° were observed.

These results indicate that the feldspar is slightly more basic than that in the Mount Hope gabbro (No. 56) described in the preceding chapter (p. 20).

A chemical analysis of the feldspar powder of No. 64, by Mr. W. S. Bayley (I in the following table), fully agrees with the results obtained by optical methods:

	I.	II.	III.
SiO_2	45.06	45.24	45.7
Al_2O_3	35.69	35.61	35.1
CaO	18.30	18.20	18.0
Na_2O	*.95	.95	1.2
	100.00	100.00	100.00
Sp. gr	2.74	2.739	2.747

* Difference.

No. II is the analysis recently communicated by Kloos[1] of the feldspathic constituent of the Ehrsberg diorite, which occurs in the southern part of Baden, intimately associated with gabbro. It is here quoted on account of its remarkable similarity to that of the Baltimore diorite. No. III is the theoretical composition of a mixture of eight molecules of anorthite with one of albite as calculated by Schuster.[2]

This feldspar melted readily in the flame of a Bunsen burner and was completely decomposed by being digested for a considerable time in concentrated hydrochloric acid.

Although the two analyses here given show the feldspars of the gabbro and diorite to be An_6 Al_1 and An_8 Al_1, respectively, still, since such slight variations in composition are well known to be common in any rock, there seems to be no reason whatever for not regarding the two feldspars as practically identical.

Under the microscope the feldspar of the gabbro-diorite exhibits finely developed twinning lamellæ, brilliant interference colors, and large extinction angles, all facts indicative of its basic character.

Inclusions are sometimes altogether absent from the feldspar; frequently, however, the same indeterminable, dust-like particles are present which have been described as occurring in the feldspar of the gabbro. Actinolite needles, evidently secondary in their origin, as well as fluid cavities containing movable bubbles, were also observed in many instances.

The fact that the feldspar is more prominent in hand specimens of the diorite than in those of the gabbro has already been mentioned. Instead of being fresh, glassy, and transparent, and therefore appearing dark from its abundant inclusions or from the color of the underlying minerals, the feldspar of the diorite is generally an opaque white, due to its more or less complete alteration to saussurite. In most cases this change is only in an incipient stage, but exceptionally the development of zoisite—to which, as Cathrein has shown, the formation of saussurite is due,[1]—has been so extensive that it is only with the greatest difficulty that the mineral can be made transparent. (Nos. 17, 74, 102.)

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[1] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. III. Beilage-Band, p. 16. 1884.

[2] Mineralogische und petrographische Mittheilungen, III., p. 153. 1881.

Closely related to the above-mentioned alteration of the feldspar is the extensive development of epidote in some specimens of the gabbro-diorite. It is especially abundant in those sections from Mount Hope, already mentioned, on account of the black inclusions contained in some of the hornblende. (Nos. 95, 96, and 110.) Sometimes the epidote crystals are scattered irregularly through the feldspar, but far more commonly they are arranged, just at the contact between the feldspar and the hornblende, in such a manner as to form a continuous border around the former, the terminated ends of the crystals projecting into the feldspar substance, as is shown on Plate III, Fig. 2.

Under the microscope, the epidote is readily distinguished from the feldspar by its wide black edge, due to its high refractive index. Between crossed nicols it exhibits the usual very brilliant interference colors. The extinction is parallel to the longest axis of the crystals and to the cleavage lines, because, although a monoclinic mineral, the individuals are, as is generally the case with this species, elongated in the direction of the axis of symmetry (orthodiagonal). The optical axes lie in the clinopinacoid $\infty P \grave{\infty}$ (010), i.e., in the plane at right angles to the longest axis of the crystal. Ordinary long sections, therefore, show in converged polarized light the interference figure of either an optical axis or a bisectrix. One exceedingly distinct section cut parallel to the clinopinacoid is reproduced on a large scale in Fig. 1. The absence of any interference figure in converged polarized light indicated the crystallographic orientation of this section. Two distinct sets of cleavage lines, parallel to OP (001) and $\infty P \bar{\infty}$ (100), respectively, intersect at an angle of 116°. The extinction angle is 5° when measured against the pinacoidal and 59° when measured against the basal cleavage. All of these observations agree so closely with the well known physical properties of epidote as to place the nature of this mineral beyond a doubt.

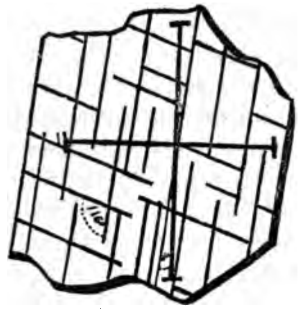

FIG. 1.—Epidote cross-section. (Slide No. 95.)

The true epidote of the gabbro-diorite is distinguished from the closely allied zoisite, mentioned above as a component of the saussurite, by its more pronounced crystal form, its peculiar mode of arrangement, the larger size of its individuals, but especially by its color and pleochroism. Moreover, the monoclinic character of this mineral, though not generally apparent, is proven by the cross-section above described and figured.

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[1] Zeitschrift für Krystallographie, VII., p. 234. 1883.

The color of the epidote is very light, and the pleochroism is proportionately weak; nevertheless both are distinctly visible. The ray vibrating parallel to the orthodiagonal axis ($\bar{b}$) is colorless, while that vibrating at right angles to it is a light greenish-yellow. Absorption, $\mathfrak{b}\ (=\bar{b}) < \mathfrak{c}=\mathfrak{a}$, which corresponds with that of a similar epidote recently described by H. Reusch as occurring in a diorite from Drontheim, in Norway.[1] No twinning lamellæ, however, like those mentioned by Reusch, were observed in the Baltimore rock.

From its position the epidote of the gabbro-diorite would appear to have resulted from the alteration of the feldspar, as has been so often observed by other investigators. Its peculiar position at the contact between the feldspar and the hornblende would furthermore indicate that the latter mineral had also participated in its formation. A similar relation was suggested by Zirkel in 1876 for epidote observed by him in certain propylites from Washoe.[2]

The other occasional constituents of the gabbro-diorite, like garnet, magnetite, apatite, rutile, sphene, &c., have already been mentioned by name and are so accessory in their character as to need no detailed description.

As regards the structure of the gabbro-diorite, it is in many respects identical with that of the hypersthene-gabbro. Where both rocks are equally massive there are the same abrupt changes in grain, the same banding produced by alternate layers richer in one or another of the mineral constituents, and the same very coarse pegmatitic varieties. Indeed, there are many localities where the color is the only macroscopical guide as to whether a given rock-specimen is gabbro or diorite.

In other cases, however, the hornblendic rock possesses a well marked schistose structure, which the true gabbro never exhibits. This is on the whole most common near the periphery of the area, especially in its southern part, although it is by no means confined to this portion. When thus foliated the rock cleaves with greater or less readiness along one plane, which, so far as observed, appears to be parallel to the foliation of the adjacent gneisses. Where this structure is most eminently developed all traces of the gabbro disappear, and the diorite has much more the appearance of one of the so-called crystalline schists than of a massive rock.

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[1] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, II., p. 179. 1883.

[2] Microscopical Petrography, p. 112, vol. VI of the Reports of the Geological Survey of the 40th Parallel under Mr. C. King. (I am indebted to Mr. J. P. Iddings, of the United States Geological Survey, for the information that nearly all of the mineral described by Zirkel in these rocks as epidote is in reality chlorite.)

CHAPTER IV.

GENETIC RELATIONS OF THE HYPERSTHENE-GABBRO AND THE GABBRO-DIORITE.

The connection existing between the two rock types which, in their most characteristic development, have received a somewhat detailed description in the preceding chapters is an exceedingly intimate one. Mineralogically they are quite distinct, but geologically they are inseparable. Everywhere the two extremes, which we have called gabbro and diorite, are bound together by intermediate varieties whose presence seems only explicable on the supposition of the original identity of the two main types. It is to this close association, which undoubtedly possesses a wide geological significance, that the principal interest of the Baltimore gabbro area attaches. To make this clear was the main object of the investigation the results of which are here communicated. The accomplishment of this necessitated, first, a careful study of the field relations of the rocks; secondly, a consideration of their chemical composition; and, thirdly, a microscopical examination of the intermediate and transitional varieties. The results of this work will be stated in the first three sections of this chapter, while a fourth will contain the conclusions regarding the origin of the rocks in question which seem best in accord with the facts observed.

§1. GEOLOGICAL RELATIONS OF THE GABBRO AND DIORITE TO EACH OTHER AND TO THE SURROUNDING ROCKS.

In spite of the close similarity in the structure between the gabbro and the gabbro-diorite which a prolonged study of these rocks in the field disclosed, their petrographical and mineralogical differences are so great and the recognition of typical specimens of either is so easy that their association at first appeared to be only accidental.

From the intimate manner in which loose blocks of both types were mingled on the surface, it was natural to suppose that the more massive of the two—the gabbro—occurred as intrusive masses breaking through the diorite, which, on account of its frequently well developed schistose structure, was at first regarded as a member of the gneissic series. To support this view it was, of course, necessary to discover some point where the contact of the two rocks was well displayed. Careful search was therefore made at all exposures within the area studied, but nowhere could any sharp line of demarkation between the two rocks be found.

Natural and artificial exposures along the streams, highways, and railroads west and northwest of the city exhibit many admirable sections, in not a few of which both rocks are present in their most typical development. In every case, however, they grade into each other by almost insensible transitions; anything like a sharp line of contact is out of the question. Between any two points where the rocks in situ can be certainly identified as belonging to one type or the other, there is a space which cannot be referred to either. In other words, a typical occurrence of the gabbro is connected with a typical occurrence of the diorite by a rock which forms a perfectly gradual passage between them. Nowhere is there any break in the continuity of the mass; geologically both rocks must be regarded as the same.

One excellent exposure where these transitions between the gabbro and gabbro-diorite are especially well exhibited is the excavation on the Western Maryland Railroad just beyond Mount Hope Station. It was made the subject of extended study and is perhaps deserving of especial description, inasmuch as it is very typical of what may be seen at almost every gabbro exposure within the entire area.

This point, which is not over five miles northwest of the city, is easy of access by train. The railroad here runs slightly north of west. The excavation, locally known as the "Blue Cut," commences 200 yards beyond the end of the station platform and exposes just 1,000 feet of rock, which, on account of the depth to which it has been blasted, is remarkable for its freshness. The huge blocks thrown out beside the road afford admirable specimens of all varieties of the gabbro.

The first exposure is on the north side, 600 feet from the station, where a typical hypersthene-gabbro appears (No. 101); this is, however, soon covered by a dark-red soil, and is not again visible for 95 feet, when it reappears as gabbro-diorite. Five feet farther on this is again replaced by the hypersthene-gabbro, and here the first contact, or rather transition, from one rock to the other may be seen. At one point the diorite is in position, and directly below it, not two inches away, is the typical gabbro. Between the two the mass is quite continuous and composed of a rock of intermediate character, which will be more particularly described beyond. (No. 105, gabbro; No. 106, diorite; Nos. 103*a*, 103*b*, and 104, transition stages taken from one large hand specimen.)

For 50 feet on the north side beyond the last-mentioned point, the typical massive gabbro is exposed, when another change to diorite is observed. The transition here takes place in a solid wall, from 10 to 12 feet in height, whose perfect continuity is beyond a question. The two rocks alternate with each other in every direction—horizontally and vertically—in the most perplexing manner, and it is frequently impossible to tell on the spot whether a given specimen is gabbro or diorite.

On the south side of the cutting the only rock exposed, as far as this point (750 feet from the end of the station platform), is diorite. At

759 feet, however, there is a change to gabbro in a solid rock wall, exactly like that just described on the north side.

Other points where similar transitions occur are: 869 feet, south side; 910 feet, north side, where the gabbro continues for only about 6 feet; and 1,000 feet, north side (Nos. 91, 92, and 93), where the diorite once more gives place to the gabbro, which continues throughout the remaining 600 feet of the cut.

Just west of the bridge which crosses this cutting the gabbro shows a decided tendency to spheroidal weathering, so often characteristic of basic massive rocks.

Both gabbro and diorite are traversed at four points by bands of a pulverent, green material, derived from the alteration of dikes of certain highly magnesian rocks, which will be more particularly mentioned in the succeeding chapter. These bands, which are like others occurring at many points within the gabbro area, here vary in width from two to thirty feet and strike northeast.

The diorite at the Mount Hope locality is, as a rule, massive. More or less distinct indications of a banded structure are observable in both rocks, the layers having a steep southeast dip and a northeast strike and being thus conformable with the direction of the above-mentioned pulverent, green beds. This structure is due only to the arrangement of the rock constituents; any signs of a true foliation are very rarely encountered in the diorite.

The principal importance of the section at Mount Hope lies in the conclusive evidence which it affords of the geological identity of the hypersthene-gabbro and the gabbro-diorite. Precisely the same evidence may be obtained at almost any characteristic exposure of the rocks. The numerous outcrops along the old Liberty turnpike or on the Windsor road, at Powhatan or at Woodberry, or at any of the other cuttings on the Western Maryland Railroad, show the same intimate association and constant alternation of the gabbro and diorite, although not always so satisfactorily as the exposure at Mount Hope. At North Bend, on the Catonsville turnpike, the diorite is admirably exhibited in a section of some length, toward the eastern end of which the gabbro may be seen passing gradually into the amphibole rock in every direction.

The huge blocks and bowlders which are so abundant in the bed of Gwynn's Falls near the Windsor road bridge may often be plainly seen to be composed partly of one rock and partly of the other, and hand specimens can even be obtained which show the entire transition.

The relation of the rocks of the gabbro area to those which surround them has already been alluded to in Chapter I. The western, northern, and northeastern limits of the area are comparatively well defined, both because the rocks lie near the surface, being covered only by the soil formed by their own decomposition, and also because the surrounding rocks here differ very much from them in appearance and character.

At some points where the contact is well exposed, as in the Western Maryland Railroad cuttings near Highland Park, dikes of the gabbro appear to diverge from the main mass and to penetrate the surrounding schists.

The limits of the gabbro area toward the south and southeast are very difficult to locate: first, because of the thickness of the overlying Cretaceous deposits and, secondly, because certain of the adjoining schists so closely resemble the most foliated forms of the gabbro-diorite.

At numerous points around the gabbro area—as, for instance, in the bed of Jones Falls, within the city limits; on the Northern Central Railroad, south of Woodberry; along the Maryland Central (Delta) Railroad, north of Guilford; on the Belan road; and on the Baltimore and Ohio Railroad, between Avalon and Orange Grove—heavy, black, schistose rocks are exposed, which the microscope shows to be composed of feldspar, compact green hornblende, quartz, epidote, and other accessory minerals. To assume that all these rocks are alteration products of the gabbro seems at present unwarranted, since they are interbedded with and pass by gradual transitions into typical biotite-gneiss. In the quarries of this latter rock on Jones Falls, just north of the city, narrow bands of this same hornblende schist may be seen to be regularly interstratified with the gneiss—an additional proof that metamorphism can produce the same ultimate result from materials originally altogether different.

Thus far no trace of either pyroxene or really fibrous hornblende has been discovered in these hornblende schists, so that no opinion whatever can be expressed regarding their relations. Nevertheless they often resemble the true gabbro-diorite so closely that when the two rocks are in contact it is impossible to say where the one begins or the other ends. They appear to pass into one another by insensible gradations, and even the microscope fails to detect any infallible characteristics by which they may be separated. The close resemblance of these hornblendic schists and gneisses to the gabbro-diorites has given rise to the greatest difficulty encountered in fixing the limits of the gabbro area, and the uncertainty regarding the exact relations of these rocks still leaves it extremely doubtful where this line should be drawn.

A similar difficulty was found by Phillips in his studies of the metamorphosed diabases of Cornwall. He says: "There can be no doubt, however, that, under certain conditions, rocks of igneous origin acquire a degree of schistosity which is often exceedingly puzzling to the geologist, as it is sometimes impossible to determine where foliated traps cease and where metamorphosed slates begin."[1]

Seriously as the existence of these hornblende schists may affect the locating of the exact boundary of the gabbro area, it fortunately has nothing whatever to do with the main question here at issue, viz, the geological identity of the hypersthene-gabbro and the gabbro-diorite as portions of one continuous mass. There is sufficient evidence at many localities within the area to convince any one who will take the pains to carefully examine it that the two rocks differ only in the form of their bisilicate constituent.

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[1] Quarterly Journal of the Geological Society, Vol. XXXIV, p. 495, 1878.

§ 2. CHEMICAL RELATIONS OF THE GABBRO AND THE GABBRO-DIORITE.

The chemical examination of these two rock types led to the same conclusions regarding their essential identity as were reached through the study of their field relations.

The analyses given in the following table, with the exception of I*a* and II, were made by Dr. Leroy McCay, of the Green School of Science, Princeton, N. J., for whose uniform kindness in rendering every possible assistance to this investigation the writer would express his feeling of deep obligation:

	I.		I*a*.	II.	III.	IV.
SiO_2	44.10	44.12	45.31	45.35	46.85	46.68
TiO_2	....	....	....	....	.30	....
Al_2O_3	24.86	24.55	24.11	16.11	20.02	17.12
Fe_2O_3	7.89	7.89	8.24	3.42	2.30	2.18
FeO	6.53	6.51	6.47	3.50	4.60	7.61
MnO	Trace	Trace	....	....	Trace	Trace
CaO	11.90	12.01	8.08	18.04	13.84	13.46
MgO	3.89	3.78	4.49	12.32	10.16	10.34
Na_2O	1.66	1.68	1.66	[a]1.26	1.32	1.75
K_2O	.24	.19	.27		Trace	Trace
H_2O	.60	.59	.70		.88	.88
P_2O_5	....	.51	....	....	Trace	Trace
Total	101.67	101.83	99.33	100.00	100.27	100.02
Sp. gr	3.044		....	2.992	2.996	3.069

[a] Difference.

No. I gives two parallel analyses of a remarkably fresh specimen of hypersthene-gabbro from the Mount Hope Cut (No. 56). It is, as may be seen from the analysis as well as from the inspection of a thin section, unusually rich in feldspar and magnetite. A calculation of the average of these two analyses, assuming the theoretical composition of the different constituents given by J. Roth, yields the following result:

	Per cent.
Bytownite (An_6Al_1)	65.55
Diallage	15.28
Hypersthene	8.03
Magnetite	11.43
Apatite	1.12
	101.41

The constituents of this rock, which were separated as completely as possible by means of Thoulet's and Klein's solutions, gave proportions by weight agreeing very closely with those obtained by calculation, viz:

	Per cent.
Feldspar	64.2
Pyroxene and apatite	23.3
Magnetite	12.5
	100.0

I*a* is an analysis of a Swedish rock from Tiberg, which is exactly analogous in mineralogical composition to the Baltimore gabbro, containing as it does plagioclase, diallage, hypersthene, apatite, a little biotite (altogether wanting in our rocks), and much magnetite. It is called a "hyperite" by Törnebohm, whose analysis is here quoted on account of its very striking resemblance to I.[1]

Analysis No. II, by Mr. W. S. Bayley, of the Johns Hopkins University, is of another specimen of hypersthene-gabbro (No. 85), containing much less feldspar and almost no magnetite. Its color is much lighter than that of No. 56, though it is not less fresh. It was found as a bowlder in the bed of Gwynn's Falls near the Windsor road bridge. So small an amount of magnetite is present that nearly all the iron is probably in the ferrous state. If this assumption be made, a calculation of this analysis gives nearly equal proportions of feldspar and of pyroxene, a result which was also obtained by a separation of the constituents.

The very great differences between the analyses I and II, especially as regards the percentages of alumina, lime, iron, and magnesia, plainly indicate what important local variations in mineralogical composition even typical specimens of the hypersthene-gabbro may exhibit. These variations are, however, due to the proportions of the ingredients present, not to any change in their nature. They would, of course, be much greater should analyses of layers visibly richer in one or another component be compared.

Analyses III and IV are of two different specimens of the gabbro-diorite. The former (No. 64) was collected at a point midway between the Western Maryland Railroad and the village of Pikesville, the latter (No. 87) from the Windsor road beyond Forest avenue. Both represent the mean of two parallel analyses. While they differ far less than those just given of the gabbro proper, they nevertheless show considerable variation in the proportions of alumina and iron, owing to the presence of more feldspar in the one and of more hornblende in the other. It will be observed that both of these analyses fall entirely within the limits of I and II.

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[1] Ueber die Geognosie der schwedischen Hochgebirge. Bihang till k. Svensk. Vet.-Akad. Handlingar. I. Stockholm, 1873 (see review, Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 657, 1873). Quoted also by J. Roth in his Petrographische Beiträge (Analysen) for 1879, p. xxxviii.

The specific gravities given in the foregoing table were determined by means of the Thoulet solution and a Mohr's balance, as suggested by Cohen.[1]

On account of the great differences which specimens of both the gabbro and the diorite were found to exhibit in their chemical composition, an attempt was made to arrive at a fair average for each. For this purpose chips of about an equal size were taken from twenty-three of the most typical specimens of gabbro, which had been collected in every part of the entire area. These were powdered together and thus a sample of fair average composition was secured. Nineteen of the most representative specimens of the gabbro-diorite were treated in the same manner, and both powders were then analyzed by Dr. McCay, with results which are given below (V, gabbro, and VI, gabbro-diorite):

	V.	VI.
SiO_2	46 85	48.02
Al_2O_3	19.72	17.50
Fe_2O_3	3.22	1.80
FeO	7.99	7.83
CaO	13.10	13.16
MgO	7.75	10.21
Na_2O	1.56	1.48
K_2O	.09	Trace
H_2O	.56	.79
Total	100.84	100.79

While slight differences in the proportions of alumina and magnesia are still noticeable, it will be at once seen that the agreement is much closer than when individual specimens are compared. It would seem reasonable to suppose that even these would, however, disappear, if the number of specimens employed in obtaining the average sample had been sufficiently increased, inasmuch as they have been so considerably lessened in the present case.

It will be observed that the two former analyses of the diorite (Nos. III and IV) are by no means so far removed from the average composition of this rock (VI) as are those of the gabbro. This can, however, hardly be regarded as more than a coincidence, since just as great variations were noticed in different specimens of one rock as in those of the other.

The identity of the feldspathic constituents of both of these rocks has already been shown on page 30. From the analyses of the rocks themselves presented in this section it seems warrantable to regard them as chemically identical, each, however, on account of differences in the proportions of its constituent minerals, being subject to variations within wide limits.

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[1] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, II., p. 87. 1883.

§ 3. MICROSCOPICAL RELATIONS OF THE GABBRO AND THE GABBRO-DIORITE.

The microscopical study of the intermediate zone, which has already been described as always occupying a position between the hypersthene-gabbro and gabbro-diorite wherever these rocks occur in close proximity, has disclosed facts of great importance in regard to their genetic relations. This zone varies considerably in width, but nowhere shows any break in the continuity of the rock mass.

Specimens of the coarser-grained varieties of the gabbro (No. 148 and others) sometimes have their pyroxenic constituents—hypersthene and diallage—surrounded by a fibrous border, which is plainly visible to the unaided eye, especially upon a weathered surface. This border is generally of a dark-green color on its outer edge and a lighter green or even white within.

The microscopical examination of thin sections prepared from the intermediate zone discloses the universal presence of this green fringe, which is only rarely macroscopically visible. Sometimes it is wholly green; sometimes it is composed of an exterior green and an interior white portion. In some cases it is most finely fibrous; in others, comparatively compact. The microscope readily shows that this border is composed, in all cases, of hornblende, differing in no respect from that which forms the most characteristic component of the gabbro-diorite. A detailed study of any intermediate zone furthermore discovers a steady increase in the width of this hornblende fringe as the diorite is approached, until the one rock finally gives place to the other by the gradual metamorphism of the pyroxenic constituents into amphibole.

Both diallage and hypersthene appear ultimately to give rise to the same product, but the process of the alteration presents important points of difference in the two cases.

The grayish or green, non-pleochroic diallage is sometimes surrounded by a very narrow rim of compact green hornblende, possessing a perfectly homogeneous, crystalline structure; in other cases the diallage is accompanied by grains and needles of hornblende having no recognizable regularity in their arrangement; but far more frequently the amphibole is finely fibrous in its structure and penetrates the diallage individual, especially in the direction of its cleavage, in such an intimate manner as to leave little doubt that it has resulted from the latter's alteration.

All three of these forms of hornblende may be observed in the interior of diallage crystals as well as around their edge. In all cases, however, there seems to be a comparatively sharp line of separation between the two minerals, no gradual transition of the substance of one into that of the other having been observed.

In some instances the diallage is intergrown with such compact, sharply defined hornblende crystals,[1] the two minerals having no crystallographic connection, that it would appear as though they both must have originally crystallized simultaneously. Nevertheless even these most compact forms of the green hornblende are so intimately connected by every conceivable transition with those finely fibrous forms, undoubtedly of secondary origin, that the study of a long series of sections served only to strengthen the first impression into a conviction that the two cannot be separated.

Almost precisely the same relations have been recently found by J. H. Kloos to exist between the diallage and the hornblende of the gabbro occurring near Ehrsberg, in the Black Forest, in Baden.[2] This investigator regards the fibrous hornblende as undoubtedly an alteration product of the diallage; but all that has a compact structure, whether it forms a fringe about the edge of the pyroxene or is present in its interior, is considered as an original crystallization, partly simultaneous with, partly subsequent to, the formation of the diallage itself. Such an assumption is, however, unwarranted in the case of the Baltimore rocks, because the forms are connected by every possible intermediate stage.

Moreover, Streng has made an elaborate chemical study of the diallage and hornblende which occur in similar relations in the gabbros of Harzburg, in the Harz Mountains,[3] the results of which show that their composition is nearly identical. If this be true, the supposition that the diallage and the hornblende are simultaneous formations necessitates the possibility of the same chemical compound crystallizing in two different forms under exactly the same conditions. This idea is rendered even more improbable in the present case by the fact that our gabbro often contains a compact brown hornblende, of undoubted original character, but probably differing considerably in composition from the diallage.

Another reason for regarding all of the green hornblende as a secondary product is the fact that, as will be shown below, the hypersthene never contains inclusions of this mineral, as would be expected if both had crystallized simultaneously. In case the green hornblende is an original constituent, we must assume that the hypersthene first crystallized from the magma, this process having been completed before the formation of the hornblende commenced. The crystallization of the diallage, on the contrary, must have progressed along with that of the hornblende; and yet not one fact could be discovered that seemed to indicate that the hypersthene was the older constituent of the two.

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[1] Microscopic section No. 139, from a specimen collected on the Baltimore and Ohio Railroad near Gray's bridge. Diallage is also intimately intergrown with the compact primary brown hornblende, as may be seen in section No. 138, from the same locality.

[2] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. III. Beilage-Band, pp. 24-33. 1884.

[3] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, pp. 943, 948, and 950. 1862.

Their relations to each other and to the other minerals point to an equal age for both.

On the supposition of the secondary nature of the hornblende, however, these facts become at once intelligible. The chemical composition of the diallage is such as to allow its direct change by paramorphism to hornblende, and this can therefore take place as readily in one portion of the crystal as in another; in the case of hypersthene, on the other hand, the addition of certain other chemical constituents, such as alumina and lime, is necessary, and these must be furnished by the feldspar, as will be shown below. Hence it is possible for the hypersthene to change to hornblende only where it is in contact with the feldspar, i. e., around its external edge.

The secondary nature of hornblende which accompanies the hypersthene is much more evident than of that occurring in connection with the diallage. This is always composed of two distinct zones, of which the inner one is made up of fine, colorless fibers, while the outer one is dark green in color, decidedly pleochroic, and comparatively compact in structure. The appearance of this fringe is represented in Plate I, Fig. 2.

The interior colorless zone is too finely fibrous to become entirely dark between crossed nicols, but the individual needles may nevertheless be seen with a high power to have a slightly inclined extinction angle. They are generally arranged with their longest axes approximately perpendicular to the edge of the hypersthene, although they are sometimes grouped irregularly or show signs of a radial arrangement. On the one side they grade so imperceptibly into the hypersthene that there can be no doubt about their having originated from its substance. These needles are so fine that no decision based on crystal form could be arrived at in regard to their nature. Their relation to the exterior green zone renders it, however, exceedingly probable that they are some form of hornblende.[1]

This exterior portion of the fringe is often quite compact for a considerable distance and displays all the characteristic features of hornblende—cleavage angle, pleochroism, extinction, &c.—in perfection. Generally with a high power a tolerably sharp line may be seen to separate these two zones; but not infrequently a single crystal may be seen to belong to both, being white at one end and green and pleochroic at the other.

It is interesting to note that the process of alteration here described shows the closest analogy with that well known to take place around the olivine in many ancient massive rocks, although, so far as I know, it is here described for the first time in the case of the corresponding bisilicate, hypersthene.

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[1] The color of this hornblende is invariably influenced by the proximity of a grain of magnetite. Here it becomes a much deeper green, showing that this mineral has contributed something to its composition, a fact which still further indicates its secondary nature. Magnetite grains are sometimes themselves fringed with a border of dark-green hornblende.

Professor Törnebohm, in his description of the diabases and gabbros of Sweden, states that the olivine of the "hyperite" occurring near Ölme is always surrounded by a double zone of secondary hornblende, the outer one being green and the inner one colorless, on which account he considers it tremolite.[1]

F. Becke describes the same phenomenon in the olivine-gabbro of Langenlois, in Lower Austria,[2] as well as in that from Rosswein, in Saxony.[3] This author regards the interior colorless zone as probably bronzite in the first instance and as anthophyllite in the second.

Both of these writers noticed that these bordering rims were only present where the olivine came in contact with the feldspar, on which account a reaction was naturally assumed to have taken place between the substance of the two minerals, resulting in the production of a silicate of intermediate composition.

No essential difference could be observed between this change of the olivine and that exhibited by the hypersthene of the Baltimore gabbro. The fringing rims occur along the contact between the hypersthene and the feldspar, and even where the latter mineral is no longer visible they seem to occupy the place where it once existed. After the study of a number of sections under the microscope this joint action of the two minerals became so evident that a chemical examination of the composition of all the different constituents was undertaken, with a view of ascertaining how nearly the secondary hornblende agreed with the diallage in composition and how far it was intermediate between the hypersthene and the feldspar.

For this purpose a moderately coarse-grained specimen from near the Windsor road bridge, over Gwynn's Falls (No. 148), was selected, in which the alteration of both pyroxenic minerals was plainly visible to the unaided eye. Under the microscope all the phenomena above described were seen to be present in great perfection.

This rock was pulverized to such a fineness that, by sifting, a powder was obtained whose grains measured from $\frac{1}{100}$ to $\frac{1}{160}$ of an inch in diameter.[4] This was then separated, by repeated treatment with the Thoulet and Klein specific gravity solutions, into four portions, each one being composed of one of the four rock constituents in a nearly pure state. Of these, I possessed a reddish-brown color and a metallic luster, and was made up, as the microscope showed, almost wholly of hypersthene; II was brownish-gray in color and contained the diallage. It was only possible to separate these two constituents by means of the borotungstate of cadmium (Klein's solution) at a high temperature. III was green in color, and could be seen under the microscope to be composed of fibrous hornblende, both white and green. IV was pure white and contained only the feldspar.

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[1] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 384. 1877.

[2] Mineralogische und petrographische Mittheilungen, IV., p. 355. 1882.

[3] Ib., p. 450.

[4] Bolting-cloth is found to be very serviceable in preparing rock powders for the separation of the constituents.

Chemical analyses of these four powders were kindly furnished at my request by Mr. W. G. Brown, lately of the University of Virginia, who has spared no pains to render them as accurate as possible. His results are as follows:

	I.	II.	III.	IV.
SiO_2	52.12	51.414	49.240	45.32
Al_2O_3	1.69	4.323	9.010	35.45
Fe_2O_3	....	....	....	.99
FeO	20.94	9.307	10.584	....
MnO	....	.043	.035	....
CaO	3.20	20.600	14.364	16.51
MgO	21.56	15.138	15.839	.50
Na_2O	....	....	....	2.41
K_2O	....	....	....	.06
Total	99.51	100.825	99.072	101.24
Sp. gr.	3.35	3.26	3.09	2.73

These analyses are not perfectly conclusive, because we have no means of knowing that the green hornblende associated with the diallage is exactly identical in composition with that which surrounds the hypersthene. A hornblende of just the composition of the diallage would be quite possible, but in powder No. III all of this mineral present in the entire rock is mixed together.

If, however, we assume that all the hornblende does possess the same composition, as seems reasonable from the agreement in all of its physical characters, we have between the diallage (II) and the hornblende (III) only such slight differences—increase in the latter of alumina and loss of lime—as have been noted by Dr. George W. Hawes[1] and Prof. B. Harrington[2] as being the frequent accompaniments of uralitization, or perhaps even its conditioning cause.

In the case of hypersthene, however, the circumstances are altogether different. Here the hornblende is intermediate in composition between the hypersthene (I) and the feldspar (IV). For it the former must have furnished the necessary iron and magnesia, while the latter supplied the alumina and lime. Thus the chemical examination of the different constituents fully bears out the interpretation already put upon the facts observed under the microscope.

(It is worth while to notice the close resemblance of the feldspar analysis (IV) made from specimen No. 148 to that of the same mineral extracted from the Mount Hope specimen (No. 56) given on page 20.)

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[1] Mineralogy and Lithology of New Hampshire, 1878, p. 65.

[2] Report of Progress of the Canadian Geological Survey, 1878, Appendix G, p. 22.

The process of alteration of both diallage and hypersthene to hornblende continues until finally all traces of the original minerals disappear and their place is wholly occupied by an irregular aggregate of needles which are large enough to be easily determinable as amphibole. In some cases (No. 103*a*) the needles in the center of such an aggregate are colorless, while those around the edge are green and strongly pleochroic, as is represented in Plate II, Fig. 1. Gradually the interior crystals also appear to turn green like the others, and the rock passes into a typical gabbro-diorite, the feldspar, which has not united with the hypersthene substance, having suffered no material change. (Plate II, Fig. 2.)

The compact brown hornblende, which exceptionally occurs as a constituent of the Baltimore gabbro, appears finally to succumb to the same changes which the pyroxene undergoes,[1] although it resists the change much longer than this. It is frequently observed quite intact when the other bisilicates are completely altered, but has itself been seen in all stages of transition to the fibrous form. One specimen from Green Spring avenue (No. 116) shows this distinctly.

In some cases this compact brown hornblende may have given rise to the corresponding green form, filled with black inclusions, which has been mentioned on page 29.

§ 4. GENERAL CONCLUSIONS.

From the evidence presented in sections 1 and 2 of this chapter the hypersthene-gabbro and the gabbro-diorite of the Baltimore region must be regarded as geologically and chemically identical. They undoubtedly represent two modifications of one continuous rock mass, which differ only in the crystalline form of the bisilicate constituent.

If, as its relations to the surrounding rocks seem strongly to indicate, this mass be considered of igneous origin, there are but two reasonable suppositions which can account for its present differentiation: either the magma originally crystallized in two modifications, or it was at first mineralogically as well as chemically homogeneous, but subsequently underwent certain molecular changes, which were caused by the new and different conditions to which it was exposed.

The latter of these hypotheses is rendered a priori the more probable by a consideration of the peculiar relations existing between the minerals pyroxene and hornblende.

These two substances have long been known to be dimorphous, i. e., identical compounds, which, like sulphur, assume different crystalline forms under different conditions. Of these forms, the one characteristic of pyroxene is more stable at high temperatures, while the hornblende form is better in accordance with ordinary temperatures. If a crystal of hornblende be fused it will assume, on again solidifying, the augitic form. The reverse of this process may often be observed in nature, in the gradual passage of pyroxene crystals to those aggregates of hornblende needles to which, over fifty years ago, Gustav Rose gave the name "Uralit."

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[1] F. Becke describes and figures a like change of compact hornblende in the kersantites of Lower Austria (Mineralogische und petrographische Mittheilungen, V., p. 157, 1883, Pl. I., Figs. 5 and 6).

In certain cases, even under the same physical conditions, slight differences in chemical composition may determine whether the pyroxenic or the hornblendic form is assumed on crystallization, as Dr. G. W. Hawes has attempted to prove by a comparison of careful analyses of both forms.[1] Dr. Bernhard Harrington has maintained, after a study of the uralitized pyroxene of Canada, that this process is always accompanied by such chemical changes and that it is to be regarded as an example of pseudomorphism, rather than paramorphism.[2]

In spite of these differences, however, it would seem that, other things being equal—i. e., where the composition of both minerals is identical—temperature alone is sufficient to determine which crystalline form is assumed.[3] It would therefore be difficult to imagine a continuous and homogeneous magma, crystallizing under precisely the same conditions in one spot, as a typical gabbro, wholly free from hornblende, and in another as a typical diorite, entirely destitute of pyroxene.

Of much more immediate bearing on the question of the origin and relations of the two rocks of the Baltimore gabbro area is the evidence furnished by the microscopical study of the forms intermediate between them (Chap. IV, § 3, pp. 40–45). Here we have ocular demonstration of the gradual passage of the pyroxene of the gabbro into the hornblende of the diorite convincing enough, in the opinion of the writer, to warrant the assertion that all the diorite, even when it contains no trace of pyroxene, has resulted by paramorphism from the former rock. The very form in which the hornblende of the diorite occurs strongly supports this view. It is never in the compact brown crystals characteristic of volcanic rocks and similar to that which is frequently associated with the pyroxene of the unaltered gabbro, but, on the contrary, always in that green modification which is most characteristic of the crystalline schists. This is, moreover, just that form which is known to result from the alteration of pyroxene, and even when it is not so finely fibrous as to merit the name of uralite its individuals are grouped together in such confused aggregates as invariably to give to a freshly fractured surface of the diorite the peculiar satiny appearance mentioned on page 27.

Such specimens, therefore, as by themselves would pass for typical diorites, composed of plagioclase and a comparatively compact green hornblende, the writer must regard, in the light of their association, as alteration forms of the hypersthene-gabbro, and hence to be designated by the name "gabbro-diorite".[1]

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[1] Mineralogy and Lithology of New Hampshire, 1878, p. 65.

[2] Geological Survey of Canada, Report of Progress for 1878–'79, Appendix G, p. 23.

[3] G. H. Williams: On the Paramorphism of Pyroxene to Hornblende in Rocks, American Journal of Science, October, 1884.

Regions more or less similar to the one near Baltimore in the character of their rocks, and quite analogous to it in the nature of the changes which these rocks have undergone, have been studied and described by Phillips in Cornwall,[2] by Reusch in Norway,[3] by Törnebohm in Sweden,[4] by Dathe[5] and Lehmann[6] in Saxony, by Becke in Lower Austria,[7] and by Kloos in Baden.[8]

Streng,[9] Wadsworth,[10] and Irving[11] have described similar changes of pyroxene to hornblende as taking place on a large scale in the ancient crystalline rocks of the Lake Superior region, while Dr. G. W. Hawes[12] and F. D. Chester[13] have discovered them in the eastern part of the United States.

In none of these cases does there seem to be any doubt entertained as to the fact or nature of the alteration. Everywhere the hornblende is readily seen to be secondary to the pyroxene, either with or without chemical change.

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[1] Another possible supposition, viz, that the diorite was the original rock and a member of the crystalline schists like the gneisses, does not seem worthy of serious attention. It might be imagined that such hornblendic schists were locally subjected to a degree of heat sufficient to have thereby lost their schistose structure, or even in places to have been so perfectly fused that they crystallized again in the form of gabbro. Such a theory is, however, quite at variance with the facts observed in the field, and even more so with those disclosed by the microscope. Whenever there is any change directly visible we have the fibrous hornblende fringing the compact core of pyroxene. *All* observations unite to prove that, if either mineral has resulted from the alteration of the other, the pyroxene must have been the original form.

[2] Quarterly Journal of the Geological Society, XXXII, 1876, p. 155, and XXXIV, 1878, p. 471.

[3] Die fossilienführenden krystallinen Schiefer von Bergen in Norwegen. German translation by R. Baldauf, 1883, p. 35.

[4] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 391. 1877.

[5] Erläuterungen zur geologischen Specialkarte des Königreichs Sachsen. Section Waldheim (No. 62), 1879, p. 35.

[6] Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine, p. 190. Bonn, 1884.

[7] Mineralogische und petrographische Mittheilungen, IV., p. 357. 1882. Becke has also described fine-grained hypersthene-gabbros, more or less altered to hornblendic rocks, as occurring in the peninsula of Chalcidice. Ib., I., p. 244. 1878.

[8] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. III. Beilage-Band, pp. 24–34. 1884.

An extremely interesting account of the small gabbro area near Rådmansö, north of Stockholm in Sweden, has very recently been published by Prof. E. Svedmark. In many respects it more closely resembles the Baltimore area than any other which has yet been described. (Geologiska Föreningens i Stockholm Förhandlingar. VII. Band, 1885, pp. 789–846, Plates 19–24, and VIII. Band, 1886, pp. 221–248.)

[9] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, pp. 133 and 240. 1877.

[10] Bulletin Museum Comparative Zoölogy of Harvard College, Cambridge, VII, p. 46.

[11] American Journal of Science (3), XXVII, February, 1884, p. 134.

[12] Ib. (3), XII, p. 136.

[14] Proceedings of the Academy of Natural Sciences, Philadelphia, October 14, 1884, p. 244.

In reference to the immediate cause producing this alteration of pyroxene to hornblende in rocks not much has been said; indeed, there seems no reason for supposing that it is in every case the same.

Both Hawes and Harrington, as has already been noted, have called attention to prevailing chemical differences between the two forms, which are undoubtedly influential in determining the original crystallization.

It has, however, been repeatedly shown by experiment that precisely the same compound will crystallize as augite at high and as hornblende at low temperatures. Augite, therefore, which is a mineral especially characteristic of lavas, in which it was formed at a high temperature, may at ordinary temperatures be regarded as a less stable form than the hornblende of a corresponding composition, although the molecular cohesion consequent upon the solid state may not be overcome by the tendency of the molecules to suit their arrangement to the altered conditions.

Such a tendency we see plainly manifested in the case of many dimorphous minerals whose crystal form depends upon the temperature at which they originated. In boracite it is shown by an intense optical disturbance without alteration of the external form; in leucite the tension is relieved by a slight distortion of the crystal angles and the production of twinning lamellæ parallel to the "slipping-planes" (Gleitflächen), which are here those of the dodecahedron, ∞ 0 (110).[1] In the case of monoclinic sulphur the whole internal structure is torn down and the original form replaced by an aggregate of needles having the orthorhombic symmetry which is more in accordance with ordinary temperatures.

The phenomena exhibited by boracite and leucite have not been observed in the case of pyroxene and amphibole, nor, indeed, on account of the relations existing between the morphological and the optical properties of these minerals, could they be expected. Crystals having the form of augite, however, but composed of needles of hornblende, often with more or less of the original substance remaining as a core in the center, were long ago described by Rose and are familiar to all mineralogists. The microscope has revealed the widespread occurrence of this change in many of the older crystalline rocks.

The *tendency* on the part of the augite molecules to change their arrangement at ordinary temperatures is therefore apparent, and this tendency may be assisted by the action of any influence which can increase the facility of their motion without raising the temperature to that degree at which the pyroxene arrangement becomes the most stable.

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[1] C. Klein: Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. III. Beilage-Band, p. 576. 1885. H. Rosenbusch: Ib., II., p. 59. 1885.

Professor J. Lehmann,[1] as well as the present writer,[2] has been inclined to ascribe the uralitization of some rocks to the action of great pressure such as might be exerted by the upheaval of mountains. It seems as though such a pressure, when extended over a very long interval, might bring about a gradual slipping and rearrangement of the molecules without any great increase of temperature.

Very recently Mr. Frederick H. Hatch, of London, has reached similar conclusions from his studies of the gabbros and derivative schistose-hornblende rocks occurring at Wildschönau in the Tyrol.[3]

As already stated[4] (p. 32), only such rocks within the Baltimore gabbro area exhibit a schistose structure as have their pyroxene *entirely* replaced by green, fibrous hornblende. By no means all of the plagioclase-hornblende rocks, however, are schistose. The larger proportion of these are as massive as the gabbros.

Pressure may and doubtless does in many instances assist in the paramorphism of pyroxene in rocks, but it cannot in all cases be regarded as even a necessary adjunct.

The rocks of the Baltimore gabbro area, for instance, do not exhibit in their individual mineral constituents the effects of having been subjected to an enormous strain. The bending and breaking of crystals and the disturbance of their optical constants, which is so often observed in the rocks of some much contorted regions, are here rarely noticed. Moreover, in those particular specimens (Nos. 99 and 147) in which these phenomena are most prominent, uralitization of the pyroxene has hardly more than commenced. The very fact that the pressure has not been as great as in certain other more disturbed areas may perhaps itself be sufficient to account for the abundant masses of the unchanged pyroxene rock occurring in the midst of its hornblendic derivative.

In point of fact we know at present almost nothing of what determines the crystalline form of the bisilicate in a molten magma, and still less do we understand the ultimate cause of the subsequent alteration of one form into the other—a change which is to be regarded as in no way allied to weathering or the degeneration of a rock, but rather as a transition from one crystalline state to another no less crystalline, dependent on some change in physical conditions.

All that can now be affirmed with certainty is that the evidence that such a change has taken place is abundant wherever crystalline rocks have been studied; moreover, there are few localities which could furnish more satisfactory and instructive material for tracing this change through all its stages than the gabbro area near Baltimore.

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[1] Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine. Bonn, 1884.

[2] American Journal of Science (3), XXVIII, p. 266. October, 1884.

[3] Mineralogische und petrographische Mittheilungen, VII., p. 83. 1885.

[4] American Journal of Science, October, 1884, p. 267.

CHAPTER V.

THE OLIVINE-BRONZITE-GABBRO, PERIDOTITES, AND ASSOCIATED SERPENTINES AND AMPHIBOLE ROCKS OF THE BALTIMORE REGION.

Olivine rocks and serpentines are more or less extensively associated with most of the larger gabbro areas which have hitherto been carefully studied and described (e. g., Harz Mountains, Saxony, Lower Austria, Scandinavia, &c.), and the Baltimore region proves to be no exception to this rule.

In many places olivine rocks are found so well preserved that their original character is beyond doubt, while from these every stage of transition may be clearly traced to those extensive deposits of serpentine and of massive actinolite or talcose rocks which are so widely distributed in and around the gabbro area proper.

The true olivine rocks occurring near Baltimore always contain bronzite and diallage, although the latter mineral is sometimes present in unimportant quantities. Feldspar is also a frequent constituent. This is rarely abundant, but as a rule it plays such an accessory rôle that the rocks in which it is present must be regarded as occupying an intermediate position between olivine-gabbros and true peridotites in which no trace of feldspar can be found.

All the rocks of this class occurring near Baltimore have a strong resemblance to each other. All are dark-brown or greenish-brown in color and have a peculiar rough appearance on the weathered surface, by which they may be recognized at a considerable distance. This is produced by the decay of the olivine, which leaves the crystals of the more stable bronzite standing out like knobs upon the surface.

These rocks are to be found at very many localities within the gabbro area (see map, Plate IV). Some of the most typical are as follows: near the tenth mile-post on the Western Maryland Railroad, between Pikesville and Howardville (Nos. 52 and 54); on the road a short distance east of Howardville Station (No. 61); on the northern edge of the gabbro area, just south of Smith avenue, about half a mile west of the Mount Washington copper mine (here very abundant) (No. 114); on the old Liberty turnpike, half a mile west of Druid Hill Park; near the junction of the old Liberty turnpike and Forest avenue; in the bed of Gwynn's Falls, at and above the Windsor road bridge (Nos. 133 and 170) (here rich in feldspar); on Green Spring avenue, north of Druid Hill Park (No. 41), (here much altered). Many other localities quite as good as those here given might be mentioned in the neighborhood of Howardville, Wetheredville, and Woodberry, along the upper part of Gwynn's Falls, and in the western portion of the area, near the Patapsco River. The rock sometimes occurs in comparatively narrow, well characterized dikes; sometimes in small oval or lenticular patches. In the latter case it is nearly always associated with serpentine, which has originated from its alteration.

A macroscopical examination of these rocks always discloses a compact greenish-black groundmass, in which are imbedded large crystals of a glistening yellow bronzite. In some cases no other constituent can be recognized with the unaided eye, but generally much smaller crystals of black diallage can be detected. Feldspar is frequently thinly sprinkled in small white grains throughout the rock, and in one specimen it was even so abundant as to make up one-third of the entire mass (No. 133).

The bronzite varies considerably in both the size and the number of its individuals. These range even in the same hand specimen from 1 to 8 millimeters in diameter. In some cases this mineral alone seems to compose nearly the entire mass of the rock, while in others it is so sparingly present as to appear quite accessory.

Cleavage plates of this bronzite are readily obtained parallel to ∞P∞̆ (010) and ∞ P (110). These always show, when examined under the microscope in parallel polarized light, an extinction parallel to the vertical (ċ) axis. In thin sections of the rock this mineral is nearly colorless, and can hence exhibit no pleochroism. In thick plates, however, this phenomenon is plainly visible, viz: ă = 𝔞 = reddish-brown; b̄ = 𝔟 = reddish-yellow; ċ = 𝔠 = green; absorption 𝔠 > 𝔞 > 𝔟. In converged polarized light, sections parallel to ∞ P ∞̆ (010) show no axial interference figure. Sections parallel to ∞ P (110) show a bisectrix indistinctly and in an oblique position. In thin sections the bronzite appears as large yellow or colorless plates. It has often a fibrous structure parallel to the vertical axis. Characteristic inclusions like those found in the hypersthene do not occur, but brightly polarizing spots with a highly inclined extinction angle are very prominent between crossed nicols when the bronzite itself is dark, although in ordinary light they are quite invisible. They seem to be due to an intergrowth of small portions of diallage substance. As alteration of the bronzite commences fine bands of serpentine are seen to be developed along cracks which traverse it. Minute fibers resembling bastite are also of common occurrence.

The diallage of the olivine rocks yields in isolated splinters cleavage plates parallel to ∞ P ∞̄ (100) and ∞ P (110). The former show in polarized light an extinction parallel to the cleavage lines, i. e., to the vertical axis, while in converged polarized light the same sections show an interference figure consisting of a single axis, which remains nearly stationary in the field when the stage of the microscope is revolved.

Sections parallel to ∞P (110) show an extinction angle of from 10° to 13° when measured against the vertical axis. In thin rock sections an extinction angle as high as 35° was observed in this mineral.

The diallage shows no pleochroism. Thin sections of it are nearly colorless, while such as are quite thick, but thin enough to transmit light, remain green in all positions, with no perceptible change in the intensity of the color when the transmitted ray is made to vibrate in different directions through the crystal.

The diallage has a much more perfect cleavage than the bronzite; it likewise presents a marked contrast to this mineral in the frequency with which twinning lamellæ occur in it. These seem to be of secondary origin, produced probably by pressure, as was also observed in the case of the diallage of the hypersthene-gabbro (see p. 22). Such secondary lamellæ are often present in great numbers and are especially distinct when the diallage crystal has been broken or bent.[1]

The feldspar is shown by all its physical properties to be bytownite. Its specific gravity, determined by the Thoulet solution and a Mohr's balance at 15° C., is 2.722. The average of a large number of stauroscopic measurements on cleavage fragments gave extinction angles on OP (001) of 19°, and on $\infty P \breve{\infty}$ (010) of 32°, values which agree well with the specific gravity. This feldspar is soluble with difficulty in concentrated hydrochloric acid and fuses readily in the flame of a Bunsen burner. This mineral shows a marked freedom from inclusions, differing in this respect from the feldspar of the hypersthene-gabbro. Wherever it comes in contact with the olivine, the peculiar reactionary rims of amphibole described by Törnebohm (see above, p. 43) are finely developed. The interior zone of these rims next to the olivine is narrow, granular, and almost colorless. Outside of this is a darker-greenish portion, having a feathery appearance; this exterior zone projects in rounded tufts into the feldspar substance, at the expense of which it has apparently been formed.

The main mass of the feldspar is not always fresh. The change which it has undergone is the interesting and unusual one to a zeolite mineral (probably scolecite), instead of the more common one to saussurite or calcite. While the larger portion of a feldspar crystal remains quite unchanged, radiating tufts or continuous bands of stout colorless needles may frequently be seen, having the appearance represented in Fig. 2. These needles show the most brilliant interference colors in polarized light, even when the section is exceedingly thin, an effect well known to be characteristic of the zeolites. The axes of elasticity, so far as could be determined under the microscope, appear to be parallel to the crystallographic axes. When treated in a section with hydrochloric acid these needles readily gelatinize before the feldspar substance is affected. Such of the feldspar as contains these needles in the greatest abundance gives off water when heated, a fact which is further indicative of the presence of a zeolite. In all particulars these needles seem to agree very closely with those which J. H. Kloos has recently described as occurring in the feldspar of the Ehrsberg gabbro from the Black Forest, Baden.[1] These he found by careful analysis to be a zeolite closely allied to scolecite. Similar alterations of feldspar in rocks have been mentioned by Höfer, who found the andesine of a melaphyre from Niederen Tatra changed to heulandite,[2] and by H. Rosenbusch, who describes the feldspar in the picrite from Schwarzenstein as changing to radiating fibers of some zeolitic mineral.[3]

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[1] See Van Werveke: Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, II., p. 197. 1883.

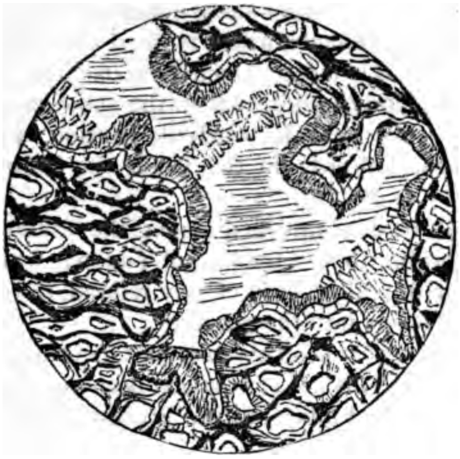

FIG. 2.—Olivine-gabbro. (No. 54.)

The olivine (the most characteristic constituent of this class of rocks) exhibits no very striking peculiarities. It is present in small rounded grains, forming the dark, compact groundmass in which crystals of the other minerals are porphyritically imbedded. The structure of these rocks is therefore quite an exceptional one for the family of peridotites: first, on account of the porphyritic character, which is rare in members of this class, and, second, because of the unusual position of the olivine in the groundmass, indicating that it is here the youngest, instead of the oldest constituent, as is generally the case. The grains of olivine are always more or less completely changed to serpentine, although in many specimens cores of the original mineral remain intact. The serpentine is of a bright-yellow color when seen in a thin section under the microscope and shows in an admirable manner the well known process of its formation out of the olivine substance. The fine serpentine fibers are developed along cracks and fissures in the olivine, working their way from these inward, until finally none of the olivine remains. A considerable quantity of magnetite in fine shreds and lines is always disseminated through the serpentine, having been separated from the olivine during the process of its alteration.

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[1] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. III. Beilage-Band, pp. 38–48. 1884.

[2] Ib., p. 145. 1871.

[3] Mikroskopische Physiographie. Vol. II. Die massigen Gesteine, p. 529. 1877.

No other constituents were observed in the olivine rocks of the Baltimore region, except in rare cases small quantities of a compact, brown, strongly pleochroic hornblende, which is filled with minute dust-like inclusions. This mineral is most intimately associated with the diallage, the two being completely intergrown in the same crystal. (Specimen No. 61, from the road near Howardville Station, and No. 79, from Gwynn's Falls near Milford; in the latter the brown hornblende is abundant.)

Three types may be distinguished among the olivine rocks of Baltimore County according to the amount of feldspar which they contain. They are, however, in reality, very closely related, the one type passing by insensible gradations into the others.

(1) *Olivine-bronzite-gabbro.*—This rock contains from 25 per cent. to 35 per cent. of feldspar. It is not of common occurrence, having been observed only in Gwynn's Falls near the Windsor road bridge (Nos. 133 and 170).

(2) *Feldspathic peridotite.*—This rock differs from the above only in the accessory rôle which the feldspar plays in it. This mineral does not compose over 5 per cent. of the rock, through which it is scattered in the form of small white particles. This is by far the commonest type of [illegible] class, and occurs at a majority of the localities mentioned on pages 50, 51.

An analysis of a fresh and typical specimen of this rock, taken from the dike on the Western Maryland Railroad, north of Howardville (No. 54), was made by Dr. Leroy McCay, of Princeton, with the following result:

	Per cent.
SiO_2	41.00
Al_2O_3	7.58
Fe_2O_3	5.99
FeO	4.63
MnO	Trace
CaO	10.08
MgO	23.59
Na_2O	.52
CO_2	3.62
H_2O	4.73
	101.74
Specific gravity	2.989

(3) *Lherzolite.*—At some localities the feldspathic constituent is altogether absent, making of the rock a true peridotite. Aggregates of olivine, bronzite, and diallage have been designated by petrographers as "Lherzolite," a name which may be properly employed in spite of the many striking differences between the rocks here described and the

original types of this class. No. 120, from an exposure recently made in opening the new highway known as Belvidere avenue, south of Mount Washington, is an example of this type in which the bronzite is much subordinated to the diallage. No. 80, from the farm of Mr. Baker on Gwynn's Falls, is a beautiful example of the same rock, though differing much in external appearance from the specimen last mentioned. It contains some diallage and many large oval crystals of bronzite, nearly 5 millimeters in diameter, which are so numerous as to render quite subordinate the dark-green, olivine groundmass in which they are inclosed. No. 174, from the Johnnycake road, is quite similar.

Another class of massive rocks is well represented in Baltimore County, which, though closely allied to the preceding, differs from it in the entire absence of both feldspar and olivine. Like the olivine rocks they give rise to serpentinous and talcose alteration products, but are themselves composed wholly of bronzite or hypersthene, sometimes with, sometimes without diallage.

In several localities very coarse-grained aggregates of long bladelike crystals of bronzite and titanic iron are encountered. As an example of this rock may be mentioned specimen No. 62, collected near the tenth mile post on the Western Maryland Railroad. In it the bronzite crystals are from twenty to thirty millimeters in length.

Comparatively fine-grained aggregates of both monoclinic and orthorhombic pyroxene, generally free from all other minerals, are also not uncommon. One in particular (No. 176), found on the Johnnycake road, deserves especial mention on account of its freshness and beauty when seen under the microscope. It is composed of a non-pleochroic, green diallage and a very strongly pleochroic, deep-red hypersthene, both in rounded grains of nearly equal size ($\frac{1}{2}$ millimeter in diameter) and both almost wholly free from inclusions. It would be difficult to conceive of the occurrence of these two interesting minerals in a purer state than in this rock.

A very similar rock to the one just described was found by the roadside near the Pikesville station (No. 100). It had evidently been brought there for road ballast, and hence its source could not with certainty be determined. In place of the pleochroic hypersthene of No. 176 this specimen contained a much paler orthorhombic pyroxene, which possesses the properties of bronzite. In other respects the two rocks are not to be distinguished from each other.

Pyroxene rocks like the above, free from both olivine and feldspar, have been described by R. Drasche as giving rise by their alteration to certain serpentines of the Tyrol and Ireland;[1] Berwerth has attributed a similar origin to some of the serpentines occurring near Rosignano and Castellina Marittima, south of Pisa, in Italy;[2] and Rosenbusch regards the serpentines of Todtmoss, in Baden, as derived from allied rocks.[1]

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[1] Tschermak's Mineralogische Mittheilungen, I., p. 10. 1871.

[2] Ib., IV., p. 238. 1876.

Many serpentines of Pennsylvania have long been known to be the alteration product of a rock composed almost wholly of enstatite.

The olivine-bearing rocks of the Baltimore region exhibit a most interesting and instructive series of alterations, the study of which has satisfactorily established the fact that masses of a similar character were the original form of a varied group of magnesian rocks common throughout the district.

Not merely in the neighborhood of Baltimore, but throughout the entire Archean belt of the Eastern United States, masses of serpentine and of asbestiform and talcose rocks are of such common occurrence that the tracing by means of the microscope of a few such types through transitional stages back to an original aggregate of pyroxene and olivine must possess more than a local interest.

Generally speaking, the olivine of these rocks changes to serpentine and magnetite; the pyroxene, whether bronzite or diallage, alters at first to a light-green or colorless hornblende, having the composition of actinolite or of tremolite. This hornblende in turn is frequently transformed into talc, accompanied by the separation of the calcium in the form of the carbonate. A series of changes nearly identical with these has recently been described in some detail by F. Becke, who has traced them in the serpentines and associated rocks of Lower Austria.[2]

All of these changes may often be very perfectly and satisfactorily traced out in a single rock-mass of small dimensions. Moreover, wherever any of the original minerals remain, they seem to be, for rocks of this class, in all cases the same. No other process of alteration could be discovered in the peridotites within the area examined; and hence it would appear quite justifiable to assume a similar origin for all such serpentines and talcose masses as are identical with undeniable alteration products of olivine rocks, even though they may not themselves contain any remnants of their original constituents.

The mineralogical composition of the final product depends, of course, upon that of the mother rock; but by a careful study of the changes to which each component is subject, both alone and in association with other minerals, it becomes quite possible to conclude what the original condition of the derived rock must have been.

The alteration of olivine to serpentine, thanks to the careful figures and descriptions of Tschermak[3] and others, is now too well known to need further mention.

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[1] Mikroskopische Physiographie. Vol. II. Die massigen Gesteine, p. 538. 1877.

[2] Die Gneissformation des niederösterreichischen Waldviertels. C. Olivingesteine und deren Begleiter. Mineralogische und petrographische Mittheilungen, IV., pp. 322–352. 1882.

[3] Sitzungsberichte der k. Akademie der Wissenschaften. LVI. Beilage-Band. Wien, Juli 1867.

Whether the less common alteration of this mineral to hornblende, as described by F. Becke,[1] also takes place in our rocks is not certain. Most of the serpentines contain considerable amphibole, but no instance has yet been observed where it could not be traced with more probability to the pyroxene than to the olivine.

In case the olivine is the only constituent which has undergone much alteration, a bronzite or diallage serpentine results, in which crystals of the pyroxene are porphyritically scattered through the serpentine groundmass. Such are specimens No. 41, from Green Spring avenue, and No. 122, from the Western Maryland Railroad near Highland Park station.

The alteration of the pyroxene of the olivine rocks seems to be at first always to some form of hornblende. Sections of many comparatively little altered specimens show under the microscope a tendency to develop colorless hornblende needles and fibers in the bronzite and diallage crystals. (See No. 120, from Belvidere avenue.) This change may be continued until no vestige of the pyroxene remains. In connection with the alteration of the olivine, it gives rise to hornblendic (tremolite) serpentines, which are by far the most abundant of the magnesian rocks of Baltimore County. To them belong the serpentines of the Bare Hills, some seven miles north of the city, which are well known for the abundance of chromite and other minerals which they contain. In sections of these serpentines unmistakable traces of diallage may sometimes be discovered, although, as a rule, colorless hornblende needles and serpentine are the only silicate minerals which are present. Rocks identical in all respects with the Bare Hills serpentines have a widespread distribution in and around the gabbro area. They are especially abundant about its edge. On the Falls turnpike, which follows the eastern bank of Jones Falls northward from the city, a considerable area of them is encountered nearly opposite Melvale. The rock has here been quarried for road ballast. Smaller masses of a similar character are very abundant along all the roads in and near the valley of Jones Falls from Lake Roland to the city. In many of these exposures the gradual transition to the little-altered olivine rock may be traced, both macroscopically and microscopically, with great clearness.

Similar conditions prevail toward the western side of the area as we approach the valley of the Patapsco River. At the western edge of the bridge at Hollofields, an interesting magnesian rock occurs, in which the original constituents, olivine and pyroxene, were arranged in parallel bands. This structure is still perfectly preserved in the alternating layers of nearly black serpentine and silvery white hornblende.

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[1] Mineralogische und petrographische Mittheilungen, IV., pp. 355, 450. 1882. Ib., V., p.163. 1883.

In this specimen (No. 197) the microscope discloses numerous unaltered remains of the original minerals.

The large area of serpentine farther to the northeast, known as Soldiers' Delight, appears to be of the same nature as that at the Bare Hills. Similar rocks also occur along the southern limit of the gabbro area in the valley of the Patapsco near Ilchester.

In many specimens of these magnesian rocks a peculiar glistening mineral is largely developed which imparts a light silvery-green luster to a freshly-fractured surface. Small scales of this substance are easily separated parallel to its one perfect cleavage. They are exceedingly soft, and show in converged polarized light a biaxial interference figure. The bisectrix is perpendicular to the cleavage surface and the optical angle is very small. Before the blow-pipe this mineral is infusible, which, together with the above-mentioned characters, clearly indicates that it is *talc.*

This alteration of hornblende to talc in olivine rocks was first described by Tschermak, who regarded the presence of olivine as a necessary condition of the change.[1] Becke has discovered the same alteration in the hornblende serpentines of Lower Austria.[2] Tremolite passes into talc, accompanied by a change of the calcium silicate to calcium carbonate.

The secondary origin of talc in hornblende may be distinctly seen in specimens No. 115*a*, collected on the new road from Mount Washington to Green Spring avenue, and No. 140, from the Baltimore and Ohio Railroad, opposite Thistle Mills, in the Patapsco Valley.

The pure pyroxene rock mentioned on page 55 as composed wholly of diallage and bronzite would be naturally expected to yield somewhat different alteration products from those derived from the olivine rocks. Finely fibrous masses of an apple-green color are not uncommon within the gabbro area. (Nos. 59, collected north of Howardville; 82, from the Liberty turnpike; 90, 109, 110, 111, and 191, from the Mount Hope railroad cutting; 118 and 119, from Green Spring avenue, and 146, from the Dogwood road.) These rocks are composed of minute hornblende needles, which are sometimes colorless, sometimes of a light-green tint when seen under the microscope. They seem to be that form of secondary amphibole known as smaragdite, and may be seen to have originated from the diallage, remnants of which still remain in several sections.

Where such smaragdite rocks contain no serpentine they have doubtless resulted from the alteration of diallage or diallage-bronzite aggregates. Such a specimen (No. 146), smaragdite rock from the Dogwood road, near the Patapsco River), was found by Mr. W. S. Bayley to contain 49.16 per cent. SiO_2; 5.63 per cent. Al_2O_3, and 10.62 per cent. iron (estimated as Fe_2O_3, although probably present wholly as FeO). The close agreement of these percentages with those of the compounds in the diallage of the gabbro specimen No. 148 (p. 44) is noticeable.

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[1] Tschermak's Mineralogische Mittheilungen, IV., p. 65. 1876.

[2] Mineralogische und petrographische Mittheilungen, IV., pp. 339, 349. 1882.

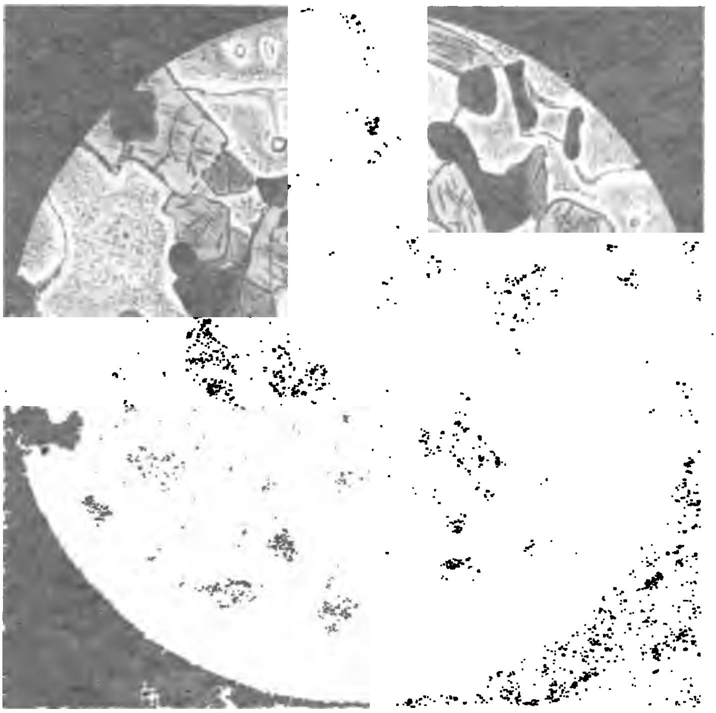
Smaragdite, agreeing closely in character with that of these Baltimore rocks, is well known to be the commonest alteration product of the diallage in many European gabbros.

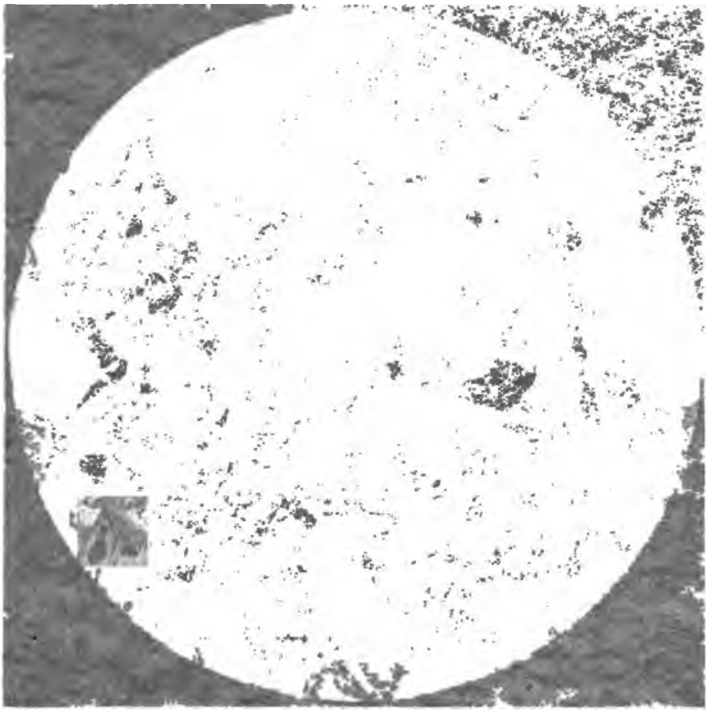
It seems possible that the asbestus deposits of Baltimore County (e. g., like the one near Elysville) may likewise be the results of the alteration of original pyroxene masses.

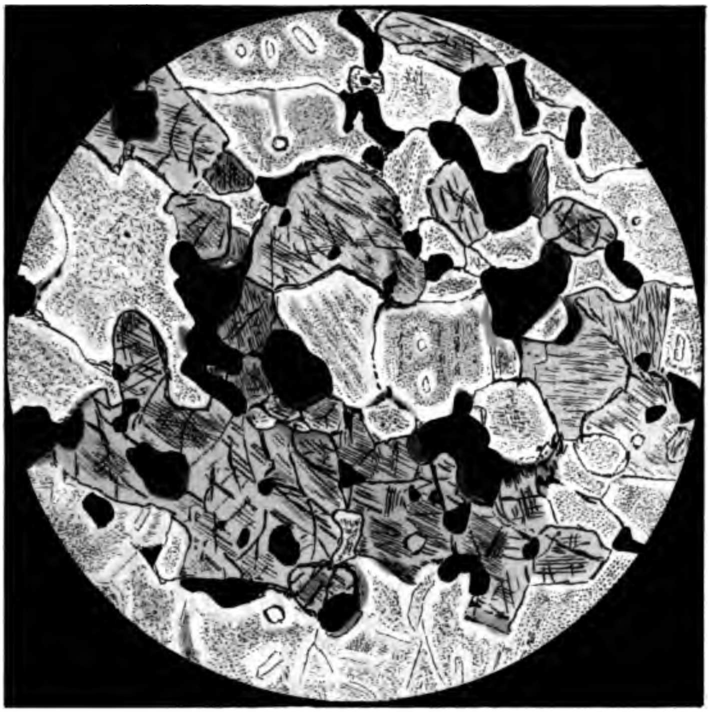
PLATE I.

Fig. 1, section of the typical hypersthene-gabbro from Mount Hope, Baltimore County, as seen under the microscope, magnified 30 diameters. The white mineral, with inclusions, is bytownite; the reddish one, hypersthene; the green one, diallage; and the black one, magnetite (section No. 91).

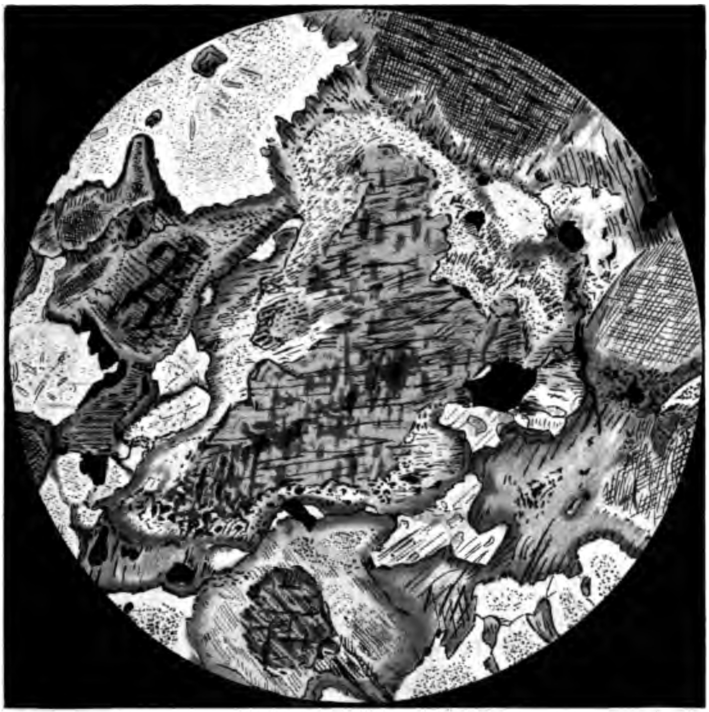
Fig. 2, section from the transitional zone, occurring between the hypersthene-gabbro and gabbro-diorite. Specimen (No. 65) collected near Pikesville; section magnified 30 diameters. The border of fibrous hornblende, surrounded by a rim of darker, more compact hornblende, is seen around both hypersthene and diallage. The characteristic differences between the secondary rims about the two minerals, described on page 42, are here well shown.







HYPERSTHENE - GABBRO.



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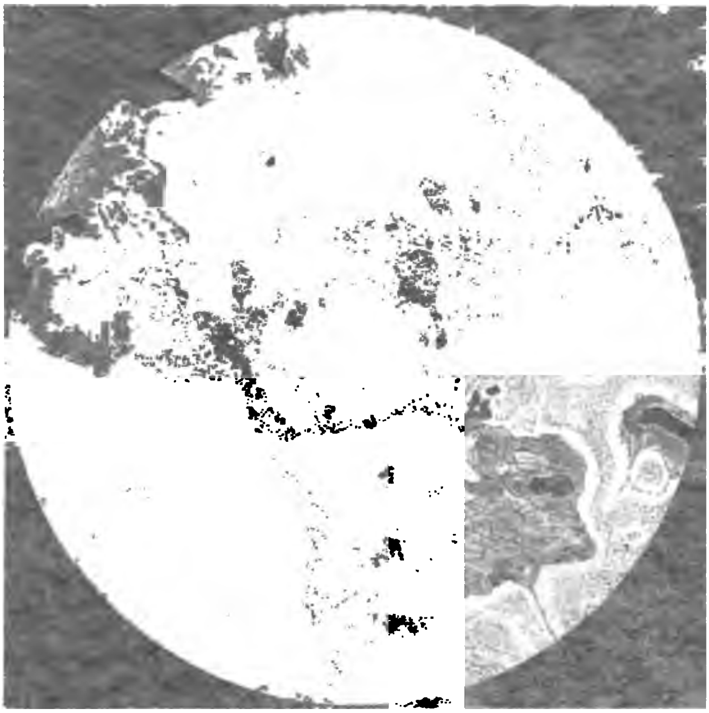
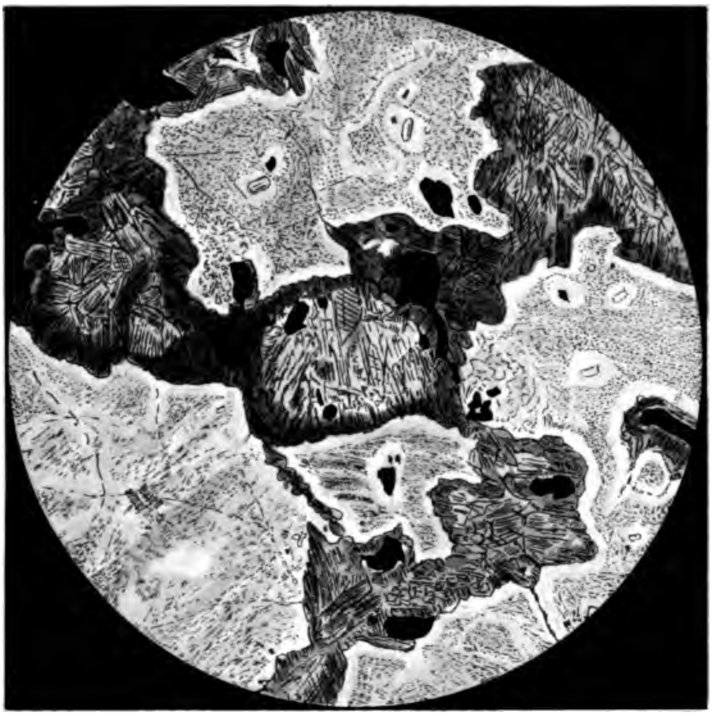
URALITIZED HYPERSTHENE - GABBRO.

PLATE II.

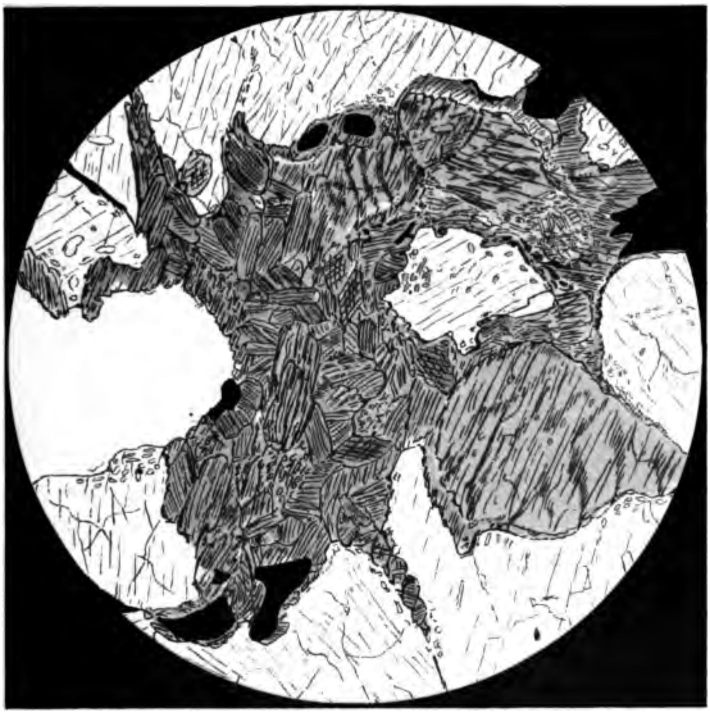
FIG. 1, section (No. 103*a*) from Mount Hope, represents the appearance of the gabbro-diorite after the total disappearance of the hypersthene. The place of this mineral is taken by aggregates of hornblende crystals, the interior ones being white and the exterior ones green, as in the case of the fringe which surrounds the hypersthene before its complete alteration. Magnified 30 diameters.

FIG. 2, section (No. 84) from the old Liberty turnpike, showing the final stage of alteration and the character of the green hornblende which is most common in the gabbro-diorite. Remains of both the hypersthene and diallage are here also seen. Section magnified 80 diameters.





GABBRO DIORITE.



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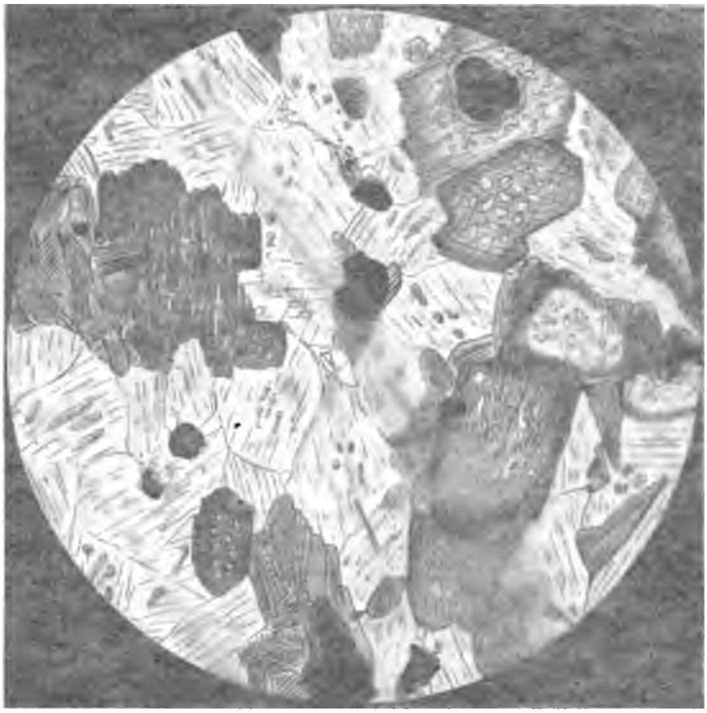
GABBRO DIORITE.

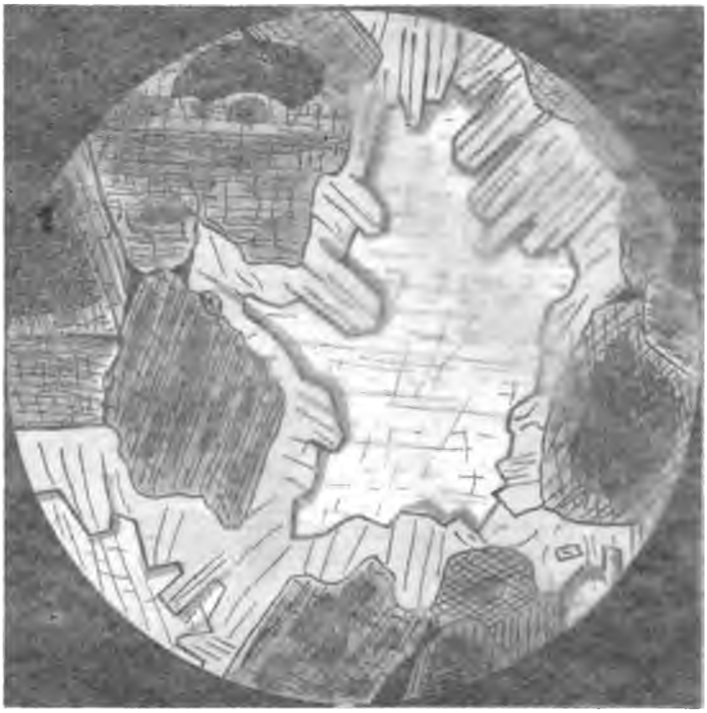
PLATE III.

FIG. 1, section (No. 92) from Mount Hope. The peculiar structure of some of the secondary hornblende of the gabbro-diorite is here represented, which is described on page 28. The exterior portion is quite compact, while the interior is made up of a fine aggregate of hornblende needles and quartz grains. Magnified 30 diameters.

FIG. 2, section (No. 95) showing the border of epidote needles surrounding the feldspar at its contact with the hornblende in the gabbro-diorite. Specimen collected at Mount Hope. Section magnified 30 diameters.



[illegible]



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LATE III

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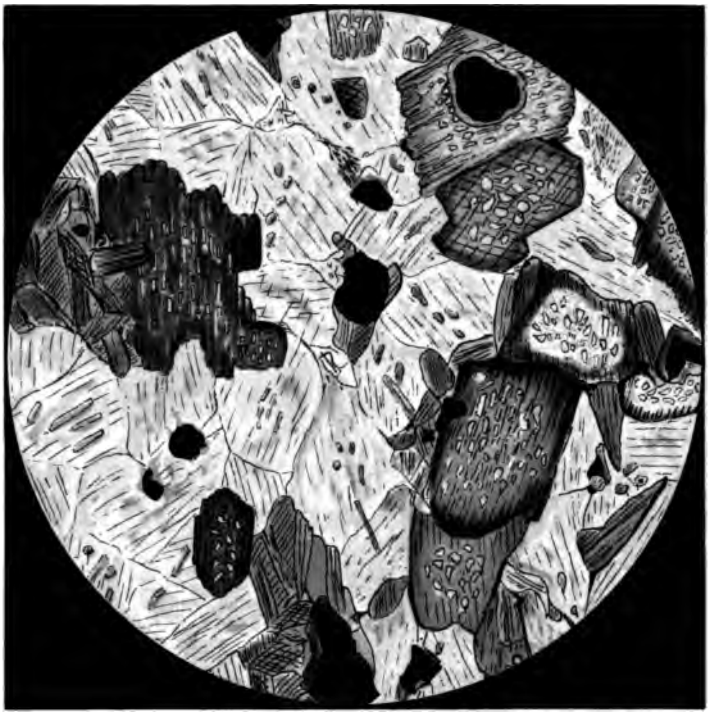

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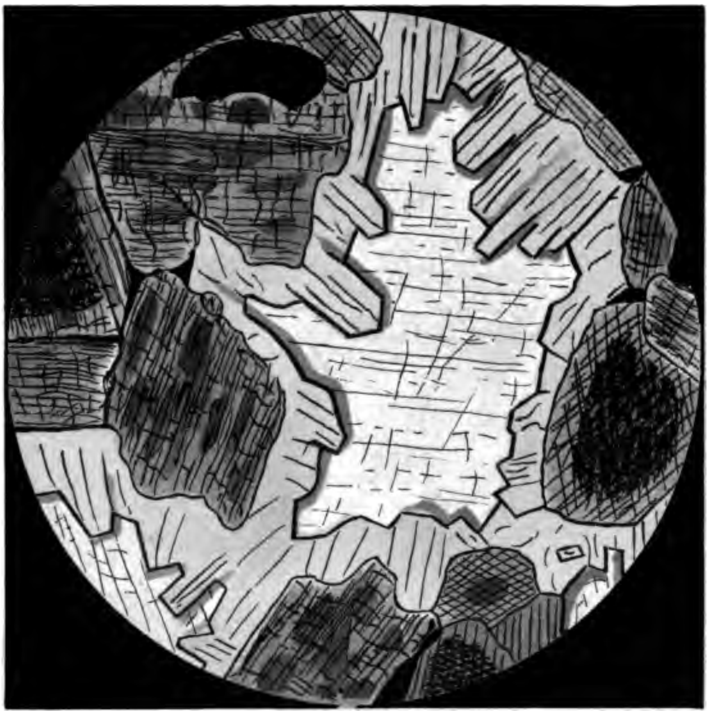

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EPIDOTE IN GABBRO - DIORITE.

PLATE III.

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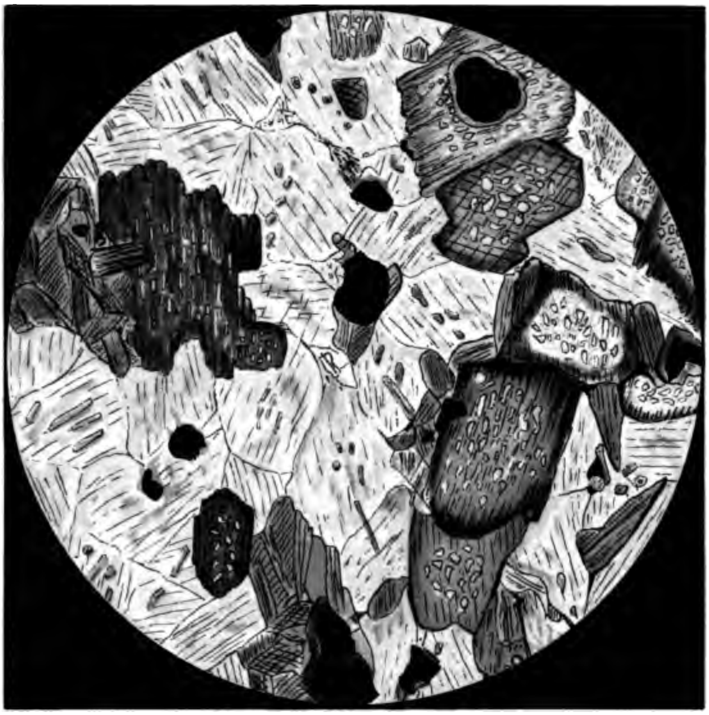
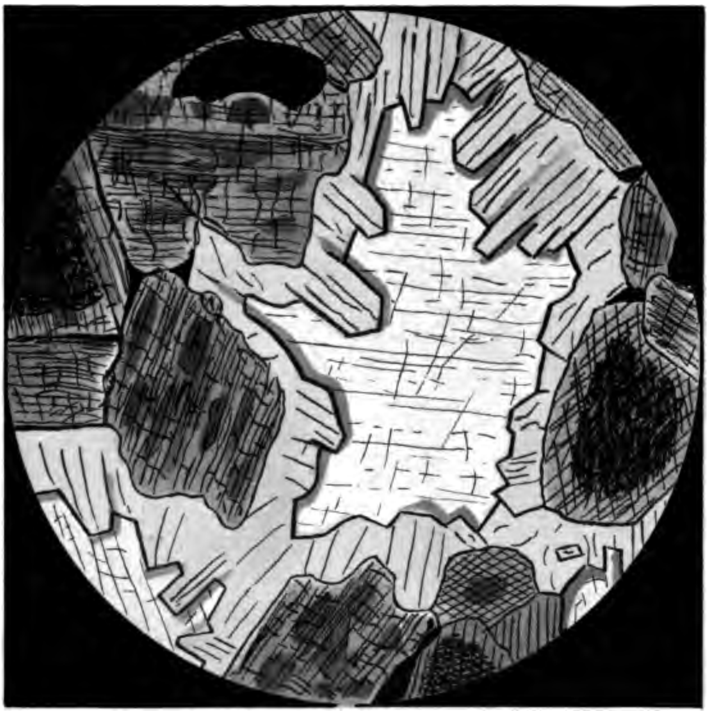


GABBRO DIORITE.



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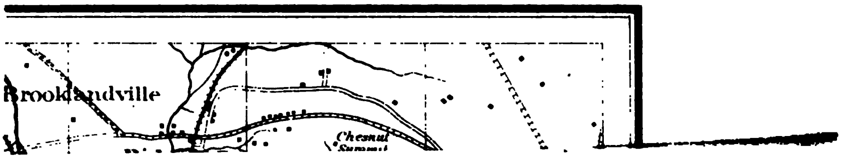
EPIDOTE IN GABBRO - DIORITE.

PLATE IV.

Geological map (as a basis for which the excursion map of Baltimore and i borhood, recently published by the trustees of the Johns Hopkins Un has been used) giving the area occupied by the gabbro and its derivativ The dotted parts of the boundary line indicate portions that could not rately located. Toward the south the overlying Cretaceous deposits impossible to fix the limits of gabbro even approximately. The most in exposures of the olivine rocks and their associated serpentines and ot nesian masses are likewise indicated upon this map.

BULLETIN Nº 28 PL IV



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DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 29

LELAND STANFORD JUNIOR UNIVERSITY LIBRARY

ON THE FRESH-WATER INVERTEBRATES OF THE NORTH AMERICAN JURASSIC

WASHINGTON
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1886

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[Bulletin No. 29.]

The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that —

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the Library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this Office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Mineral Resources and Dictionary of Altitudes, the Survey has no copies of any of its publications for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880-'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth and Sixth Annual Reports are in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, and VIII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt. U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-Lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

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The following are in press, viz:

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. ix, 338 pp. 35 pl.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. —, — pp. 56 pl.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl.

XII. Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons.

The following are in preparation, viz:

I. The Precious Metals, by Clarence King.

— Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

— Lake Bonneville, by G. K. Gilbert.

— Sauropoda, by Prof. O. C. Marsh.

— Stegosauria, by Prof. O. C. Marsh.

— Geology of the Quicksilver Deposits of the Pacific Slope, with atlas, by George F. Becker.

— The Penokee-Gogebic Iron-Bearing Series of North Wisconsin and Michigan, by Roland D. Irving.

— Description of New Fossil Plants from the Dakota Group, by Leo Lesquereux.

— Younger Mesozoic Flora of Virginia, by William M. Fontaine.

— Report on the Denver Coal Basin, by Samuel F. Emmons.

— Report on Ten-Mile Mining District, Colorado, by Samuel F. Emmons.

— Report on Silver Cliff Mining District, by Samuel F. Emmons.

— Flora of the Dakota Group, by J. S. Newberry.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of Annual Reports or Monographs.

Each of these Bulletins will contain but one paper and will be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient sizes. To facilitate this, each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 29 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining value of troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. A Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary studies, by Charles Doolittle Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett, 1885. 8°. 135 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

15. On the Mesozoic and Cenozoic Paleontology of California, by Dr. C. A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the higher Devonian Faunas of Ontario County, New York, by J. M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 10 cents.

17. On the Development of Crystallization in the Igneous Rocks of Washoe, by Arnold Hague and J. P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Dr. C. A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.

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19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White, M. D. 1885. 8°. 25 pp. 5 pl. Price 5 cents.

23. The Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary fossils and recent forms from American localities between Cape Hatteras and Cape Roque, including the Bermudas, by W. H. Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The Present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 82 pp. Price 10 cents.

26. Copper Smelting, by Henry M. Howe. 1885. 8°. 107 pp. Price 10 cents.

27. Work done in the division of Chemistry and Physics mainly during the fiscal year 1884-'85. 1886. 8°. 80 pp. Price 10 cents.

28. The Gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Md., by George H. Williams. 1886. 8°. 78 pp. Price 10 cents.

29. On the Fresh-water Invertebrates of the North American Jurassic, by Dr. C. A. White. 1886. 8°. 42 pp. Price 5 cents.

Numbers 1 to 6 of the Bulletins form Volume I; Numbers 7 to 14, Volume II; Numbers 15 to 23, Volume III; and Numbers 24 to 30, Volume IV. Volume V is not yet complete.

The following are in press, viz:

30. Second contribution to the studies on the Cambrian Faunas of North America, by Charles D. Walcott.

31. A systematic review of our present knowledge of fossil insects, including Myriapods and Arachnids, by Samuel H. Scudder.

32. Report of the Mineral Springs of the United States, by Albert C. Peale.

33. Notes on the Geology of Northern California, by J. S. Diller.

34. On the relation of the Laramie Molluscan Fauna to that of the succeeding Fresh-water Eocene and other groups, by Dr. C. A. White.

35. The Physical Properties of the Iron Carburets, by Carl Barus and Vincent Strouhal.

36. The subsidence of small particles of Insoluble Solid in Liquid, by Carl Barus.

STATISTICAL PAPERS.

A fourth series of publications, having special reference to the mineral resources of the United States, has been undertaken.

Of that series the following have been published, viz:

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1,016 pp. Price 60 cents.

In preparation:

Mineral Resources of the United States for calendar year 1885, by Albert Williams, jr.

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To the Director of the
United States Geological Survey,
Washington, D. C.

Washington, D. C., *May* 15, 1886.

DEPARTMENT OF THE INTERIOR

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No. 29

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1886

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

ON THE

FRESH-WATER INVERTEBRATES

OF THE

NORTH AMERICAN JURASSIC

BY

CHARLES A. WHITE, M. D.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1886

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FRESH-WATER INVERTEBRATES OF THE NORTH AMERICAN JURASSIC.

By CHARLES A. WHITE.

I. GENERAL REMARKS.

Important additions having lately been made to our knowledge of the fresh-water invertebrates of the North American Jurassic strata, I have thought it desirable to present not only descriptions and figures of the new forms in this bulletin, but to make the publication an illustrated synopsis of all the forms yet discovered. I therefore reproduce on the accompanying plates figures of all the species hitherto published, in addition to those of the new forms. Besides this, I offer the following general discussion of the subject of those fresh-water fossils and their bearing upon continental history.

Among the earliest collections of fossils made from the Jurassic rocks of North America, Meek and Hayden recognized certain of the species as belonging to such fresh-water genera as *Unio*, *Viviparus*, *Lioplacodes*, *Planorbis*, and *Valvata*.[1]

The specimens referred to these genera were collected by Dr. Hayden in the region of the Black Hills of Dakota, and, although he felt quite sure that they came from Jurassic strata, the rock specimens which contained the fossils were detached from their original ledges, and no rediscovery of the species in situ has since been made unless some of the forms described in this bulletin shall prove to be identical. Subsequently I described a species of *Unio* from some fragments which were discovered in Jurassic strata near the banks of Green River, Wyoming, by Mr. J. F. Steward, a member of an exploring party then in charge of the present Director of the U. S. Geological Survey.[2] Still later, I republished with figures all the species which have just been referred to.[3] Besides these fossils, which were published by Meek and Hayden and myself, respectively, no fresh-water invertebrate fossils have hitherto been publicly announced as coming from the Jurassic strata of North America.

---

[1] Palæontology of the Upper Missouri, Meek and Hayden; Smithsonian Contributions, 1864.

[2] Report on the Geology of the Uinta Mountains, J. W. Powell, p. 10.

[3] Review of the Non-Marine Fossil Mollusca of North America, Third Annual Report of the U. S. Geological Survey, p. 426, Pl. 3.

I have no reason to doubt that the five species which were published by Meek and Hayden really came from Jurassic strata; but, even if it should hereafter appear that they are of later age, the following remarks in relation to our fresh-water Jurassic fauna are warranted by our present knowledge of species which come from strata the Jurassic age of which is known.

No division of the Jurassic strata of Western North America into an upper and a lower series has been suggested upon paleontological grounds by those who have written upon the invertebrate fossils which they are found to contain. Professor Marsh was the first to divide those strata paleontologically, which he did in consequence of the marked difference he found to exist between the vertebrate fossils that characterize the upper and the lower series respectively. It is probable, however, that when our Jurassic invertebrates come to be fully known, those upper and lower divisions respectively will be found to show a corresponding difference. There is also a lithological difference between the strata of the two divisions, which, while it is not pronounced, is usually more or less distinctly recognizable.

In an article which I lately published[1] I remarked that no invertebrate fossils, so far as I was aware, had up to that time been found in the upper or Atlantosaurus division of the Jurassic. That remark would have been more nearly correct if it had contained the statement that no invertebrate fossils had been published as coming from that division of the Jurassic; and I was soon afterward reminded of this technical error by a letter from Professor Marsh. He then also informed me that his collectors frequently met with fresh-water molluscan forms while quarrying for vertebrate fossils in the Atlantosaurus beds, and at the same time he sent me some Uniones and a small gasteropod. A part of these fossils had been obtained from his Jurassic quarries at Como, Wyo., and a part of them from those near Cañon City, Colo., all of them coming from the Atlantosaurus beds.

The inference being a natural one that these few forms were members of a contemporaneous fauna which embraced a considerable number of other species, I visited the quarries, in both Colorado and Wyoming, from which they were obtained, for the purpose of personal observation and collection, and I was rewarded by the discovery of several additional species at the Colorado locality, which, together with others, are described and figured in this bulletin. By the aid of Mr. M. P. Felch, who for several years past, under the direction of Professor Marsh, has obtained from the Jurassic rocks near Cañon City such remarkable collections of dinosaurian and other vertebrate remains, I was able to determine accurately the horizon of the invertebrates with relation to that of the vertebrates. In fact I found them both to occupy the same horizon, the layers bearing the invertebrates alternating with those bearing the vertebrates, some of the species of the former ranging through several of the layers. A portion of the specimens of *Unio* contained in the collections which were made near Cañon City were found in a layer immediately above the uppermost one in which dinosaurian remains have yet been found there; but other specimens of the same species were found beneath that layer, associated with the gasteropods, showing that even the species referred to began its existence before the extinction of the Jurassic dinosaurs. The other species, including all the gasteropods, were found beneath a greater or less number of layers bearing dinosaurian remains. In short, the observed conditions were such as to leave no room for doubt that the vertebrate and invertebrate faunas whose remains are found there lived contemporaneously. This statement is emphasized here because these fresh-water invertebrate species of Jurassic age are so modern in type that of themselves they offer no suggestion of greater age than the Tertiary.

---

[1] American Journal of Science, Vol. XXIX (3), p. 228.

The horizon of the fresh-water Jurassic mollusca which were found at Como, Wyo., was pointed out to me with equal precision by Mr. Kennedy, who has for many years collected vertebrate fossils there for Professor Marsh, and their position in the Atlantosaurus beds was ascertained beyond question by my personal observation.

Several years ago I also visited the locality from which Mr. Steward obtained the fragments of *Unio* referred to in a previous paragraph, and, although I was not able to make any further discoveries there, nor to determine with precision the layer from which Mr. Steward obtained his specimens, I believe them to have come from the equivalent of the Atlantosaurus beds. I have never visited the locality in the region of the Black Hills from which Dr. Hayden obtained his Jurassic fossils, and I have therefore no certain information as to whether they came from the Atlantosaurus beds or not.

The apparent identity of one or two of those species from the Black Hills with some which were found at the Cañon City locality, and of one or two of the species from the latter locality with some of those at Como, suggests an identity of horizon at the three localities; but, even if the identity referred to is real, the horizon of each locality may be more or less different, for it is believed that some of the species then existing may have passed from one horizon to another, even as certain fresh-water species are now known to have passed from the Laramie up into the Wasatch group. The character of the strata in which these fresh-water Jurassic fossils were found, both at the Colorado and at the Wyoming localities, in addition to the character of the fossils themselves, is such as to indicate for them a lacustrine, and not an estuary or a fluviatile, origin; that is, the rocks are regularly stratified and have such an aspect and character as to indicate that they were deposited in one or more large bodies of water. If the strata of the Colorado and of the Wyoming localities really contain an identical fauna, it may be regarded as at least probable that they were deposited in one and the same lake. The distance between the Colorado and the Wyoming localities indicates that the supposed lake was nearly 200 miles across; and, if the Black Hills fossils also belonged to the same contemporaneous fauna, the assumed lake was much larger. The existence of a fresh-water lake of even the smaller size suggested makes it necessary to infer that there was then in that part of the North America of to-day a continental area of considerable size, for such a lake could hardly be other than a part of a large drainage system. But, aside from these considerations, the existence of such fresh-water faunas as are represented by these collections, whether in large or in small bodies of water, indicates with hardly less clearness than the proved existence of one great lake would do the synchronous existence of a large continental area. Indeed it seems necessary to assume that in the fresh waters of a large land area alone could faunas of such a character as those which are represented by these collections be developed and perpetuated.

The inference that there was during the Jurassic period a great North American land area, which seems to be so fully warranted by the presence in those strata of the fresh-water invertebrates which are illustrated on the plates of this bulletin, is supported with equal force by the evidence which is afforded by the large collections of vertebrate remains that have been brought out by Professor Marsh. These show that there existed then a large proportion of vegetable feeders and other land denizens among the widely differentiated dinosaurs, besides a not inconsiderable mammalian fauna.

The belief has prevailed among geologists that the great interior portion of the present continent of North America, now occupied by Mesozoic and later strata was, until the close of the Cretaceous period, continuously occupied by an oceanic belt which separated a large western from a large eastern continental area. That portions of this assumed intercontinental marine area were really occupied by marine waters at different times during the Paleozoic and Mesozoic ages cannot be doubted, because of the marine character of the deposits which are found there. The facts which have just been stated with reference to Jurassic faunas, however, plainly indicate that a large part of that area was above the sea during the Jurassic period.

There are other facts which indicate that the great interior region in question was the scene of extensive shiftings of land and sea during the whole of Mesozoic time, and until its final incorporation with adjacent areas to form the present North American continent. Reference is here made to the breaks or omissions in the order of succession of the formations which are now found upon either side of that portion of the region in question, which lies between the thirty-eighth and the forty-fourth parallels, the omitted formations being absent over extensive areas. If we go to the western or Rocky Mountain portion of this great interior region, we find the Triassic rocks resting upon the Carboniferous, and the Jurassic and the Cretaceous formations following them in their order, the strata of all three of these periods being there more or less fully developed. Coming then to the eastern side, to the region of the ninety-sixth meridian, or that which is traversed by the middle portion of the Missouri River, we find the lowest member of the Cretaceous resting directly upon the Carboniferous, the Triassic and the Jurassic being absent in all that region.

The intervening space between that region and the eastern base of the Rocky Mountains is occupied by the Great Plains and the prairie region with which they blend to the eastward; in all, some six or eight degrees of longitude in width. No natural exposures of either Jurassic or Triassic strata have been found upon either the Great Plains or the prairies. Still, it is clear that these two formations extend for some distance to the eastward beneath the plains, because they are so conspicuously present at their western border, the foot of the mountains.

The only positive knowledge we have yet obtained as to the existence of those strata beneath the plains is derived from an artesian boring made by order of the United States Agricultural Department, at Fort Lyon, Colo.[1] This locality is about one-third of the distance across the plains proper, eastward from their western border, the base of the Rocky Mountains. At Fort Lyon the boring passed first through the lower member of the Cretaceous, then through the Jurassic and into the Triassic. The Jurassic strata there have less than half the thickness which they reach in the Rocky Mountain region. This shows so rapid a thinning of that formation to the eastward that its eastern border is probably only a few miles farther eastward than the Fort Lyon boring. How far the Triassic extends eastward beneath the Great Plains is not known, but probably not farther than does the Jurassic. The Cretaceous rocks are doubtless continuous beneath the whole surface of the plains, for they have been found exposed at the surface at several points upon them, and also at many points farther eastward, in Kansas and Nebraska. They are also known to exist in Iowa, not only in the western part of the State, but in the northern and northeastern portions also, as well as in adjoining parts of Minnesota and Dakota.

The facts thus presented indicate remarkable westward advances and eastward recedences of the western coast line of the eastern continental area during Mesozoic time. These movements were remarkable for their great geographical extent in both directions, for the slight evidence of littoral action which the strata present, for the comparatively slight vertical extent of the movements, and for the absence of evidence of any correlated orologic displacements. It is not asserted that a definite history of these sea-border movements has been ascertained, but the following suggestions seem to be warranted by the stratigraphical conditions which are known to exist now, a part of which has just been mentioned. At the close of the Carboniferous age there was a great westward extension of the eastern continental area, and during the Triassic and Jurassic periods that area had extended its western border to near the one hundred and third meridian. Immediately upon the close of the Jurassic and at the beginning of the Dakota epoch of the Cretaceous, that border retreated eastward, so that parts of it at least reached as far eastward as the ninety-fifth meridian. A little later, in the Colorado epoch of the Cretaceous, the maximum eastward extension of the Cretaceous sea occurred, which carried a portion of it as far eastward as the ninety-third meridian, in what is now the northeastern portion of Iowa and the southeastern portion of Minnesota. Before the close of the Colorado epoch a rapid retreat to the westward of the Cretaceous sea border was begun, and by the close of that epoch it seems to have reached as far westward as about the one hundredth meridian. At the close of the Fox Hills epoch of the Cretaceous, at least a very large part of the area which was then occupied by marine waters became the seat of the great inland Laramie sea, and true marine waters then finally disappeared from the interior of the present continent.

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[1] Artesian Wells upon the Great Plains. Department of Agriculture: pamphlet, pp. 38 and geological map. Washington, Government Printing Office, 1882.

It is true that the evidence as to the nature and extent of these alternate eastward and westward movements of oceanic and continental borders is not so complete as could be desired, but it is believed that the considerations which have just been presented are fully justified by the stratigraphical conditions referred to, and that their correctness will not be doubted by geologists who may have observed those conditions. That a large part of that interior region, together with other portions of the present continent, was above the level of the sea during the Jurassic period, especially in the latter part of it, seems to be equally certain. Indeed, in view of the evidence we have (derived from both the vertebrate and invertebrate fossils mentioned in preceding paragraphs) of the existing continental conditions and in view of the limited extent of recognized marine Jurassic deposits in North America and the doubtful age of some of the deposits which have been referred to that period, one cannot say with confidence that any considerable part of the present North American continent was beneath the sea during any portion of the Jurassic period. In conclusion, I think it may be safely assumed that the great inland portion of our continent was not so permanently the seat of oceanic waters during Mesozoic time as has been supposed.

II. DESCRIPTION AND CITATION OF SPECIES.

Descriptions of the new species which have lately been obtained from Colorado and Wyoming are given upon following pages, accompanying which are citations with remarks upon all the other fresh-water invertebrates hitherto published from the Jurassic rocks of North America. The object in presenting the previously published forms together with the new is, as before remarked, to give a synopsis of all the known fresh-water fossils which have been discovered in our Jurassic rocks.

It is to be expected that other forms will yet be discovered, because the Jurassic deposits which are now known to be of fresh-water origin are quite extensive, and also because the forms which are at present known almost certainly do not constitute a complete fauna. So large a proportion of the discovered species belong to types that are common among living faunas that we naturally look for such other types among the fossil species as are usually associated with their living congeners. For example, having two typical species of *Limnœa*, we expect to find *Physa* associated with them; and, having the palustral pulmonates so well represented, we naturally expect to find representatives of the land pulmonates also. Besides the forementioned types which these Jurassic collections embrace, the somewhat numerous examples of Unionidæ and Viviparidæ among them add still further to their modern aspect. Indeed, so modern is the facies of the Jurassic fauna, as represented by the collections here discussed, that one is surprised to find only a single type among them which is not common among American living fresh-water species, and this type is referred to the Limnæidæ. Still, in view of the great age of these fossils, it may be expected that some types will yet be found which living faunas do not contain.

MOLLUSCA.

UNIONIDÆ.

All the species of the Unionidæ which have been found in the Jurassic rocks of North America, the hinge characters of which have been seen, belong to the genus *Unio* proper; and all the others doubtless possess the same generic characters. They also all belong to the simpler types of that genus as regards their outward shape; and all of them have the surface plain or without wrinkles, tubercles, or other ornamentation except the ordinary lines of growth. Most of them depart but little from the transversely oval shape which is so common among both living and fossil species, and none of them possess features which separate them, except specifically, from numerous known Tertiary and living forms. The rugose and tubercular ornamentation, such as is common among the living Uniones of the Mississippi River system, has not been observed upon any members of the family of earlier date than the Laramie period. I have elsewhere expressed the opinion that the Unione fauna of the Laramie group are ancestrally related to the living Unione fauna of the Mississippi River system, and that the genetic line of descent was preserved through the persistence of rivers during succeeding geological epochs.[1]

It is not improbable that the genetic relationship of the living and of the Laramie Uniones extends back to the Jurassic period, and that it includes those which are herein described and figured. None of these Jurassic Uniones, however, have features which distinguish them as to type from plain forms, both living and fossil, which are found in various other parts of the world, while a considerable part of the Laramie species are of distinctively North American types.

UNIO FELCHII (sp. nov.).

Plate I, Figs. 1, 2, 3, 4, and 5.

Shell transversely elongate, suboval in marginal outline, short and somewhat narrow in front of the beaks, higher behind them, elongate and narrowing towards the posterior end; basal margin gently convex or nearly straight, and usually a little emarginate just behind the mid-length of the shell; front margin regularly but somewhat narrowly rounded; dorsal margin long behind the beaks and broadly convex from the beaks to the posterior end, short in front of the beaks, declining to the anterior end; posterior margin narrowly and regularly rounded; beaks situated near the front, depressed so that the greatest height of the shell is a little behind them; umbones somewhat broad; umbonal ridges not defined; valves moderately convex; surface plain; ligament long and prominent.

Length of an adult example, but not quite the largest in the collection, 80 millimeters; height, 44 millimeters; convexity, both valves together, 20 millimeters. Some of the examples which were found associated with the typical adult forms are more nearly oval in outline, but they are regarded as the young of this species.

This species belongs to one of the plain types of the Unionidæ which prevails among both fossil and recent forms. The type to which it belongs also embraces *U. clinopisthus* White, from the Green River Eocene group of Southern Wyoming, the living *U. gibbosus* Barnes, &c. Indeed, if it were not for the known horizon from which this species comes and its association with dinosaurian remains, one could not say with certainty that it is of earlier date than the Tertiary. A considerable number of specimens of this species have been collected, and it seems to have lived in great abundance. The specific name is given in honor of Edward Felch, the young man who first discovered this species, together with the following one.

Locality and position.—Atlantosaurus beds, 8 miles north of Cañon City, Colo., where it is associated with the following species and with all the gasteropods which are herein described from that locality.

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[1] Review of the Non-Marine Fossil Mollusca of North America, C. A. White, p. 78.

UNIO TOXONOTUS (sp. nov.).

Plate II, Figs. 1 and 2.

Shell suboval in marginal outline, short and narrow in front of the beaks, elevated and convex behind them, where the shell has its greatest height, narrowing rapidly towards the posterior end; basal margin broadly convex; front and posterior margins narrowly rounded; dorsal margin strongly convex, sloping abruptly downward both before and behind; beaks depressed, situated near the front; umbones broad; the sides of the valves having the ordinary convexity, but the dorsal border of each is so much inflexed in adult examples as to hide the ligament from side view. Surface plain, being marked only by the ordinary lines of growth.

Length, 60 millimeters; height, 39 millimeters; convexity, both valves together, 28 millimeters.

Locality and position.—Atlantosaurus beds, 8 miles north of Cañon City, Colo., where it is associated with the preceding species.

UNIO MACROPISTHUS (sp. nov.).

Plate II, Fig. 7.

Shell rather small, irregularly oblong in marginal outline, the front portion being conspicuously narrower than the posterior portion; basal margin broadly emarginate; front margin rounded from the base to the short antero-dorsal margin; postero-dorsal margin somewhat regularly rounded from the beaks to the postero-basal margin, which is more narrowly rounded to the base; beaks not prominent, situated subcentrally, or a little nearer to the front than to the posterior end; valves somewhat irregularly convex, the median portion being flattened or compressed at the base. Surface plain, being marked only by the ordinary lines of growth.

Length of the most perfect example obtained, 33 millimeters; height behind the beaks, 24 millimeters.

The specimens which are referred to this species were found only in a layer of soft sandy shale, and only in the condition of natural casts. One of these specimens shows the general features of the interior of the shell, and others show its external form. The specimens are imperfect, but the more important features of the shell are so well preserved that it is referred to a distinct species with much confidence.

Locality and position.—Atlantosaurus beds, 8 miles north of Cañón City, Colo.

UNIO IRIDOIDES (sp. nov.).

Plate II, Figs. 3 and 4.

Shell rather small, moderately elongate transversely, subelliptical in marginal outline; valves somewhat regularly convex; beaks small, not prominent, situated at a little more than one-quarter of the length of the shell from the front; basal margin broadly convex; front margin regularly rounded; dorsal margin proper comparatively short; postero-dorsal margin longer and sloping downward to the posterior end. Surface plain.

Length of the largest example in the collection, 45 millimeters; height, 27 millimeters.

Some natural casts of this species were found in the layer of soft sandy shale associated with the preceding species and also the two following ones; but the largest example, which is figured on Plate II, was obtained from a higher layer, where it is associated with *U. Felchii* and *U. toxonotus*. This larger example has the natural surface preserved, and in general aspect it resembles an *Anodonta*, but the other examples show the characters of true *Unio*. This species is referable to the plain elongate type so common among living American Uniones, approaching in shape the *U. iris* of Lea as closely perhaps as any other species; for which reason the specific name *iridoides* has been chosen for the fossil form.

Locality and position.—Atlantosaurus beds, 8 miles north of Cañon City, Colo.

UNIO LAPILLOIDES (sp. nov.).

Plate II, Figs. 5 and 6.

Shell rather small, transversely elongate, subelliptical in marginal outline; basal margin broadly convex or straightened along its median portion; front margin regularly rounded; dorsal margin gently convex; postero-dorsal margin broadly convex and sloping downward to the narrowly rounded posterior margin; valves having considerable convexity; beaks small, slightly prominent, situated at about one-third the length of the shell from the front. Surface plain, being marked only by the ordinary lines of growth.

Length, 36 millimeters; height, 17 millimeters.

This species, like the last, belongs to the elongate-oval type, and, although it is a somewhat larger shell than the living *U. lapillus* of Say, it approaches that species as closely perhaps as any other well known form. All the specimens yet found are in the condition of natural casts, which are more or less imperfect; but the features of the shell are sufficiently well shown to indicate a well marked species among the Jurassic Uniones.

Locality and position.—Atlantosaurus beds, 8 miles north of Cañon City, Colo., where it is associated with the two preceding species in the bed of soft sandy shale which has already been mentioned. An example from a similar layer in the Atlantosaurus beds at Como, Wyo., although much distorted by pressure, seems also to belong to this species.

UNIO STEWARDI White.

Plate III, Figs. 1 and 2.

Unio Stewardi White, 1876. Report on the Geology of the Uinta Mountains, J. W. Powell, p. 110.
Unio Stewardi White, 1883. Review of the Non-Marine Fossil Mollusca of North America, C. A. White, in the Third Annual Report of the United States Geological Survey, p. 426, Pl. 3, Fig. 1.

Associated with the three foregoing species in a layer of soft sandy shale at the locality 8 miles north of Cañon City, Colo., some examples were found which seem to belong to the species which I published (op. cit.) under the name of *U. Stewardi*. This identification is doubtful, however, on account of the imperfection both of the specimens above referred to and of those upon which the species was originally proposed. The last named specimens, which were obtained from Jurassic strata near the banks of Green River in Southern Wyoming, being all fragmentary, served only to construct the restored outline, which is given on Plate III. The Colorado specimens evidently belong to the same type, if not to the same species, as *U. Stewardi*. They are also too unlike any other form now known to exist in our Jurassic rocks to make any other reference more satisfactory.

UNIO NUCALIS Meek & Hayden.

Plate III, Figs. 3, 4, 5, 6, and 7.

Unio nucalis M. & H., 1858. Proceedings of the Academy of Natural Sciences, Philadelphia, 1858, p. 52.
Unio nucalis M. & H., 1865. Palæontology of the Upper Missouri, p. 92, Pl. III, Fig. 13, a, b, c.
Unio nucalis White, 1883. Review of the Non-Marine Fossil Mollusca of North America, in the Third Annual Report of the United States Geological Survey, p. 426, Pl. 3, Figs. 2, 3, and 4.

The original specimens of this species were obtained by Dr. Hayden from the region of the Black Hills of Dakota, and they were the first specimens of that genus to be referred to the American Jurassic. Among the specimens sent by Professor Marsh from the Atlantosaurus beds at Como, Wyo., are some natural casts of a shell which belongs to the same type and probably to the same species. A considerable number of these casts have been found at Como, all of which are of smaller size than the average of the original specimens of *U. nucalis*. The specimens are all too imperfect for one to base a specific description upon them or to refer them with confidence to any known species. Fragments of the shell found with the casts show that the species is one of true *Unio*.

LIMNÆIDÆ.

Genus LIMNÆA Lamarck.

LIMNÆA ATIVUNCULA (sp. nov.).

Plate IV, Figs. 10 and 11.

Shell small, spire moderately slender; volutions about six in number, convex, the last one enlarged and somewhat longer than the spire. Surface marked by the usual lines of growth.

Length of the largest example in the collection, 8 millimeters; but their average length is considerably less.

The younger examples of this species are more slender than the adult specimens on account of the proportionally greater enlargement of the last volution upon reaching maturity. These younger examples are so slender as to suggest their reference to *Acella*, but the older shells have more the shape of true *Limnæa.*

Locality and position.—Atlantosaurus beds, 8 miles north of Cañon City, Colo.

LIMNÆA CONSORTIS (sp. nov.).

Plate IV, Figs. 8 and 9.

Shell moderately small; spire short; volutions about five in number, convex, the last one inflated and much longer than the spire. Surface marked by the usual lines of growth.

Length of the largest example, 10 millimeters; breadth of the last volution, 5 millimeters.

This species, although small, is somewhat larger than the one last described, and it is also more robust than is usual with species of this genus, approaching *Physa* in that respect.

Locality and position.—Atlantosaurus beds, 8 miles north of Cañon City, Colo.

LIMNÆA? ACCELERATA (sp. nov.).

Plate IV, Figs. 12, 13, 14, and 15.

Shell elongate ovoid; aperture a little shorter than the spire in adult shells; sides of the spire convex, rounding in more or less abruptly toward the apex, but when perfect the extreme apex is small and prominent; volutions convex, seven or eight in number when the shells have reached adult size, those near the apex being narrower and more transverse than the last two, during the production of which the axial extension of the shell was proportionally more rapid than in its earlier stages. Surface plain, being marked only by fine lines of growth.

Length, 20 millimeters; diameter of the last volution, 7 millimeters.

It is apparent at a glance that this shell is not a typical *Limnæa;* but after careful comparison with several other generic forms which have a similar facies, I have not been able to refer it to any of them satisfactorily, and I therefore place it provisionally under *Limnæa*. Some of the specimens show a considerable deposit of callus upon the inner lip, in which case the flexure of the lower portion of the columella has something of the appearance of a fold such as some of the smooth forms usually referred to *Melanopsis* possess. That feature also suggests the relationship of this shell to *Stolidoma*, but there is no evidence that the axis of the spire has been absorbed, as is usually the case with the Auriculidæ. The character of the aperture also seems to render its reference to any of the Bulimidæ improper.

The collection contains a considerable number of small examples, which I at first regarded as belonging to another species; but after comparing them with the apical portion of the form here described I am quite convinced that they are the young of this species and represent the apical portion of the adult shell.

Locality and position.—Atlantosaurus beds, 8 miles north of Cañon City, Colo., where it is associated with the two preceding and with the following species.

Genus PLANORBIS Muller.

PLANORBIS VETERNUS Meek and Hayden?.

Plate IV, Figs. 20 and 21.

Planorbis veternus M. & H. Proceedings of the Academy of Natural Sciences, Philadelphia, 1860, p. 418.

Planorbis veternus M. & H., 1865. Palæontology of the Upper Missouri, p. 107, Pl. IV, Figs. 1a, 1b, and 1c.

Planorbis veternus White, 1883. Non-Marine Fossil Mollusca of North America, in the Third Annual Report of the United States Geological Survey, p. 446, Pl. 3, Fig. 6.

A large number of small specimens of a small *Planorbis* were found associated with the specimens of *Limnæa* previously described in the Atlantosaurus beds 8 miles north of Cañon City, Colo., which are referred with some doubt to the *P. veternus* of Meek and Hayden, from the region of the Black Hills of Dakota. While it is not improbable that these Colorado specimens belong to a distinct species, it is not thought advisable at present to propose a new specific name for them. The principal difference between these and the Dakota specimens seems to lie in the less rapid increase of the diameter of the volutions of the Colorado specimens.

Genus VORTICIFEX Meek.

VORTICIFEX STEARNSII (sp. nov.).

Plate IV, Figs. 4, 5, 6, and 7.

Shell small; spire nearly flat, the apex being only slightly elevated; umbilicus moderately large, rapidly narrowing inward; volutions, after the first two at the apex, rapidly increasing in width at right angles to the plane of the coil, strongly convex above, rounding abruptly into the umbilicus below, and bearing a prominent obtuse peripheral angle along the middle; suture deeply impressed; surface marked by numerous strong lines or small costæ of growth which have a convex backward curve upon the upper side of the volutions, and cross the space between the peripheral angle and the umbilicus with a concave backward curve.

Only a single example of this species has yet been found. It was sent by Professor Marsh from the Atlantosaurus beds at Como, Wyo. This specimen is very small, and has the appearance of having had a portion of the outer volution broken away, only three volutions remaining. The full adult size of the shell is therefore unknown. There seems to be no reason to doubt that this shell is strictly congeneric with the forms to which Meek gave the name *Vorticifex.* The only other known species of this genus occur in the Miocene Truckee Group of Northern Nevada and Southern Idaho.

The specific name is given in honor of Dr. R. E. C. Stearns, of the United States National Museum.

VALVATIDÆ.

Genus VALVATA Muller.

VALVATA SCABRIDA Meek and Hayden?

Plate IV, Figs. 1, 2, 3, and 19.

Valvata scabrida M. & H. Palæontology of the Upper Missouri, p. 113, Pl. IV, Figs. 2a, 2b.

Shell rather large; spire more or less depressed; volutions about five in number, convex, a transverse section of them at any point being almost a true circle; umbilicus rather small, deep. Surface marked by lines of growth which are conspicuous on well preserved examples.

Greatest diameter of an adult example, 13 millimeters; height, 11 millimeters; but in some cases the height is proportionally less.

The specimens which were described by Meek and Hayden (op. cit.) were not only imperfect, but they were small, and apparently represent only the apex of adult shells. This is certainly the case if the specimens here described belong to the same species, because they are very much larger. The apex of these large Colorado specimens compares so closely with the type specimens of Meek and Hayden that for the present I think it undesirable to propose a new specific name for them.

Locality and position.—Atlantosaurus beds, 8 miles north of Cañon City, Colo., where a large number of examples were found. The specimens described by Meek and Hayden were found near the Black Hills of Dakota.

VIVIPARUS GILLI Meek and Hayden.

Plate IV, Fig. 17.

See Palæontology of the Upper Missouri, Meek and Hayden, page 115, Pl. V, Figs. 3 a, 3 b, and Review of the Non-Marine Fossil Mollusca of North America, C. A. White, in the Third Annual Report of the United States Geological Survey, p. 470, Pl. 3, Fig. 8.

LIOPLACODES VETERNUS Meek and Hayden.

Plate IV, Fig. 18.

See Palæontology of the Upper Missouri, Meek and Hayden, page 116, and Review of the Non-Marine Fossil Mollusca of North America, C. A. White, in the Third Annual Report of the United States Geological Survey, p. 470, Pl. 3, Fig. 9.

NERITINA NEBRASCENSIS Meek and Hayden.

Plate IV, Fig. 16.

See Palæontology of the Upper Missouri, Meek and Hayden, page 109, and Review of the Non-Marine Fossil Mollusca of North America, C. A. White, in the Third Annual Report of the United States Geological Survey, p. 457, Pl. 3, Figs. 10 and 11.

Copies of Meek and Hayden's figures of these three species are given on Plate IV for the purpose of grouping together in this bulletin illustrations of all the fresh-water species which have been referred to the Jurassic of North America. These three forms, together with *Planorbis veternus*, *Valvata scabrida*, and *Unio nucalis*, were obtained by Dr. Hayden from the region of the Black Hills of Dakota, and the three whose names and places of publication are above given have not hitherto been found elsewhere. The *Neritina* is included here with the fresh-water forms, with which it seems to have been found associated.

CRUSTACEA.

OSTRACODA.

Multitudes of minute ostracods were found in the few layers of impure limestone of the Atlantosaurus beds near Cañon City, Colo., associated with the gasteropods which are described on the preceding pages. These, like the molluscan shells, are silicified; but by dissolving fragments of the limestone in hydrochloric acid the shells were liberated.

Desiring the opinion of the best authority concerning these ostracods, I sent a parcel of them to Prof. T. Rupert Jones for that purpose, and received the following reply, together with seven selections from the parcel of specimens which were sent to him:

"I have examined your specimens, and regarding them as internal casts my conclusions may be stated as follows:

"(1) *Metacypris Forbesii* Jones. Quart. Jour. Geol. Soc., XLI, p. 345, Pl. VIII, Figs. 15 and 16. A short subglobose form, even rounder than Figs. 15 and 16.

"(2) *Metacypris Forbesii.* Ib., Fig. 11. This is even longer in proportion than our most oblong form.

"(3) *Metacypris* ——? This form is narrow, oblong, and compressed, and bears a distant resemblance to '*Cypris? conculcata*' Jones, Quart. Jour. Geol. Soc., XVI, p. 266, Pl. XVI, Figs. 3, a, b.

"(4) *Darwinula leguminella* E. Forbes. Quart. Jour. Geol. Soc., XLI, p. 346, Pl. VIII, Figs. 30 and 31.

"(5) *Cypris Purbeckensis?* Forbes sp. Quart. Jour. Geol. Soc., XLI, p. 347, Pl. IX, Fig. 3.

"(6) *Cypris* ——? Indeterminate; imperfect.

"(7) *Cypris* ——? Not determined; probably new."

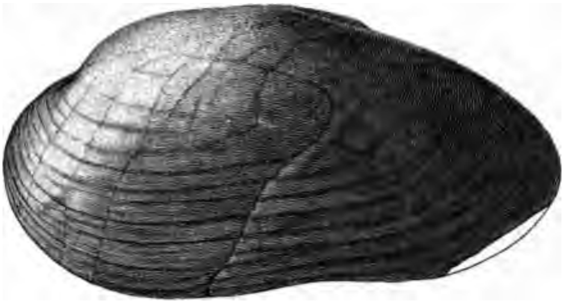
It is the intention of Professor Jones to make a further study of these forms; but it will be seen by his foregoing remarks that he regards these Rocky Mountain ostracods, so far as they have been determined, as being specifically identical with forms which he and others have published from the Purbeck formation in England. The "*Cypris? conculcata*," with which he compares the unnamed form No. 3, is from a fresh-water formation near Bahia, in Brazil, which I refer to the Neocomian in a work prepared for publication by the Brazilian Government.

Figures 22, 23, and 24 on Plate IV of this bulletin represent the form which Professor Jones refers to *Metacypris Forbesii;* and Figures 25 and 26 represent the variety No. 2 of his foregoing notes. I have not attempted to illustrate the forms referred to in his notes Nos. 3, 4, 5, 6, and 7.

PLATE I.

UNIO FELCHII.

Fig. 1. **Right side view of an adult example.**
Fig. 2. **Dorsal view of the same.**
Fig. 3. **Left side view of another example.**
Fig. 4. **Left side view of still another example.**
Fig. 5. **Dorsal view of the same.**
All natural size.



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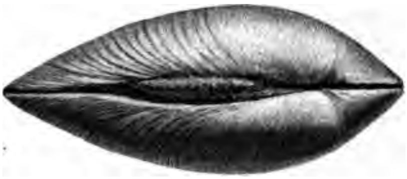

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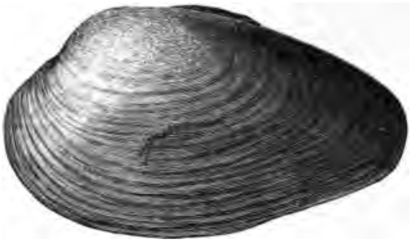

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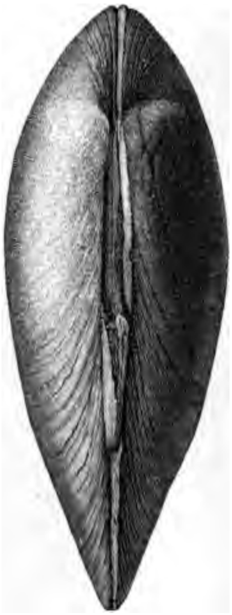

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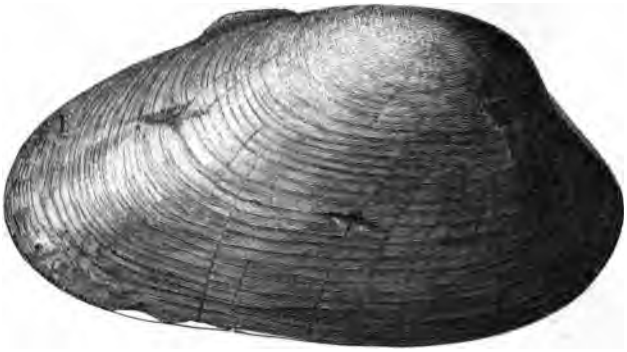

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LAMELLIBRANCHIATA

PLATE II.

UNIO TOXONOTUS.

Fig. 1. Right side view of an old example.
Fig. 2. Dorsal view of the same.

UNIO IRIDOIDES.

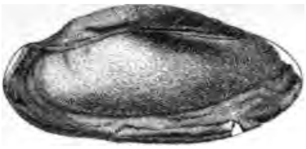
Fig. 3. Right side view of the largest example found.
Fig. 4. Similar view of a natural cast of a smaller example.

UNIO LAPILLOIDES.

Fig. 5. Left side view of a natural cast from near Cañon City, Colo.
Fig. 6. Upper view of a crushed example from Como, Wyo.

UNIO MACROPISTHUS.

Fig. 7. Left side view of a natural cast.
All natural size.



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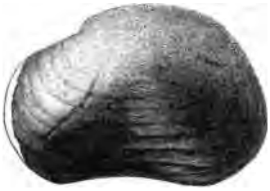

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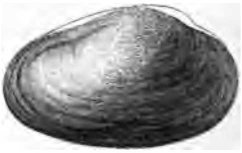

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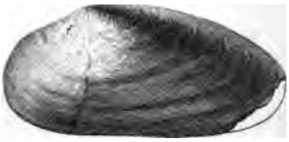

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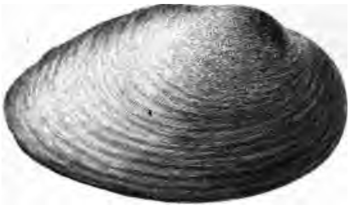

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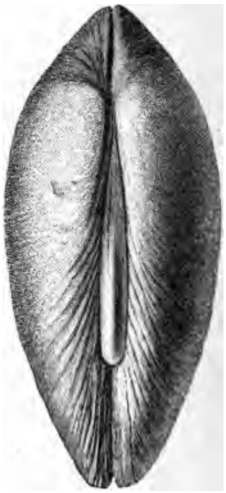

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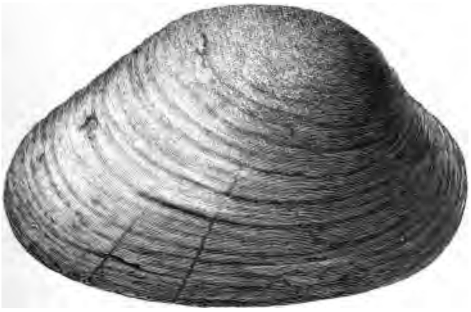

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LAMELLIBRANCHIATA.

PLATE III.

UNIO STEWARDI.

Fig. 1. Restored outline made from fragments of shells found in Southern Wyoming.

Fig. 2. Left side view of a natural cast from near Cañon City, Colo.; probably belonging to this species.

UNIO NUCALIS.

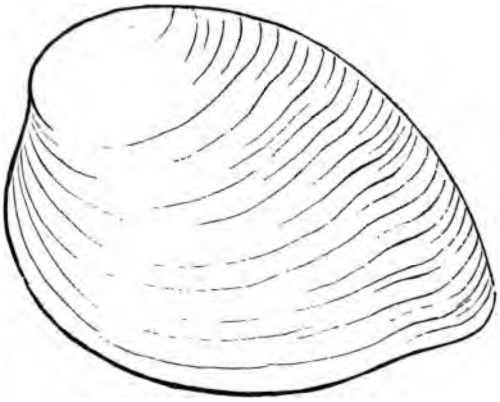
Fig. 3. Lateral view of a left valve partially restored from a specimen which is a little crushed.

Fig. 4. Dorsal view of the same, the right valve being restored in symmetry with the left.

Fig. 5. Dorsal view of one of Meek and Hayden's original types, somewhat restored, the specimen being a little crushed.

Figs. 6 and 7. Two imperfect natural casts from Como, Wyo., probably belonging to this species.

All natural size.



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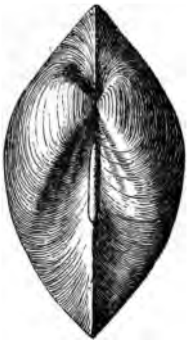

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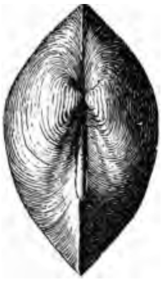

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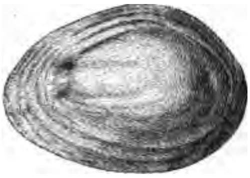

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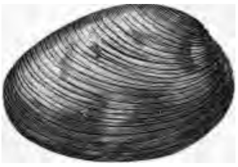

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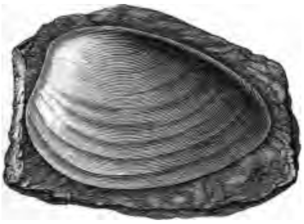

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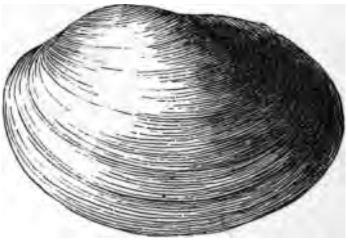

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LAMELLIBRANCHIATA.

PLATE IV.

VALVATA SCABRIDA.

Figs. 1, 2, and 3. Three different views of an example from near Cañon City, Colo., probably belonging to this species; somewhat enlarged; see also Fig. 19.

VORTICIFEX STEARNSII.

Figs. 4, 5, 6, and 7. Different views of the type specimens; much enlarged.

LIMNÆA CONSORTIS.

Fig. 8. Lateral view of a broken example; enlarged.
Fig. 9. A similar view of a smaller example; enlarged.

LIMNÆA ATIVUNCULA.

Fig. 10. Lateral view of one of the larger examples; enlarged.
Fig. 11. A similar view of a smaller example; enlarged.

LIMNÆA? ACCELERATA.

Figs. 12 and 13. Two views of an example nearly perfect; enlarged.
Fig. 14. The apical portion of a shell, showing the rapid increase in width of the two last volutions; enlarged.
Fig. 15. Apical portion of another example, showing the minute prominent apex, which is usually broken off; enlarged.

NERITINA NEBRASCENSIS.

Fig. 16. Copies of Meek and Hayden's original figures.

VIVIPARUS GILLI.

Fig. 17. Copies of Meek and Hayden's original figures.

LIOPLACODES VETERNUS.

Fig. 18. Copies of Meek and Hayden's original figures.

VALVATA SCABRIDA.

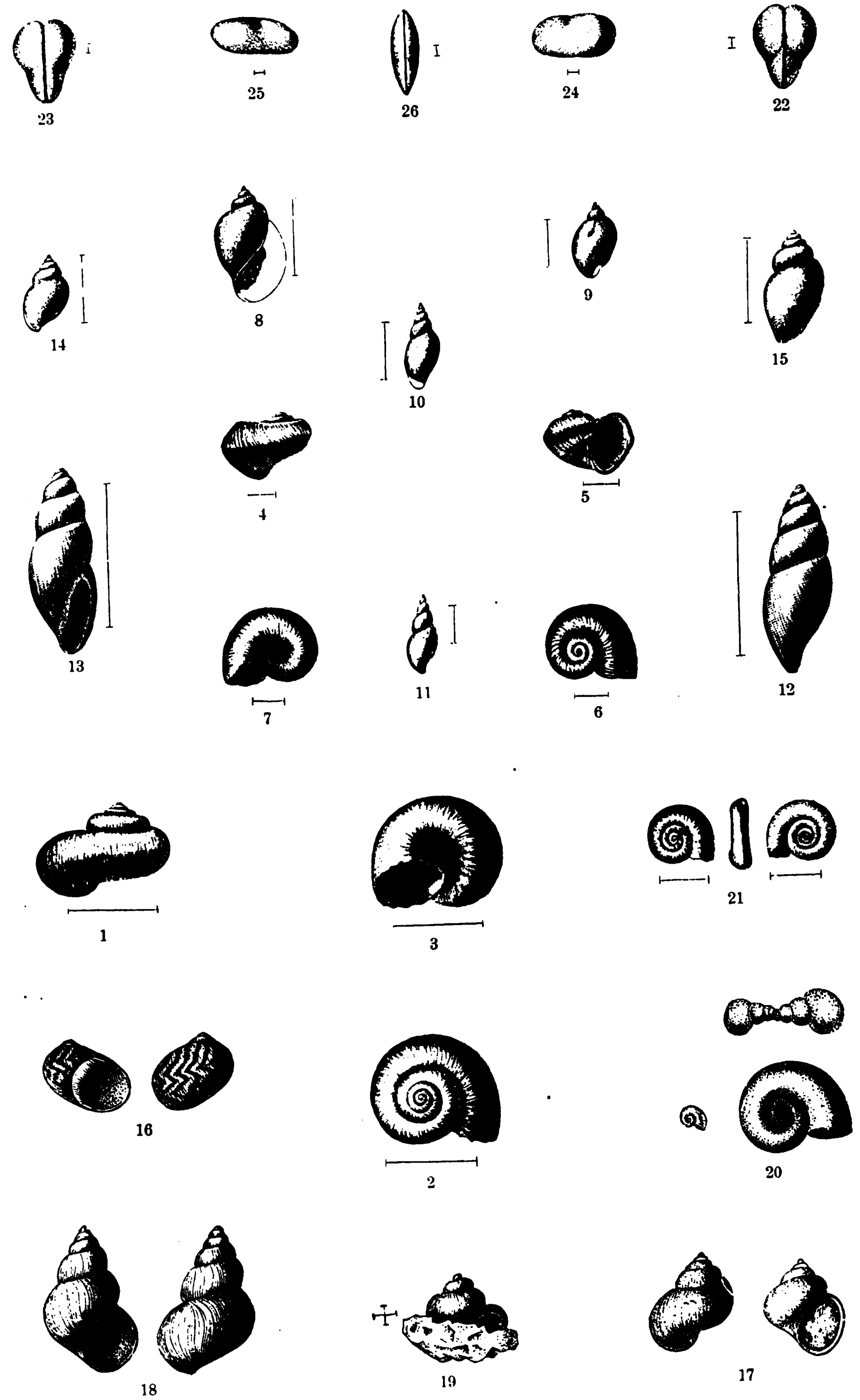
Fig. 19. Copies of Meek and Hayden's original figures; see also Figs. 1, 2, and 3.

PLANORBIS VETERNUS.

FIG. 20. Copies of Meek and Hayden's original figures.
FIG. 21. Different views of Colorado specimens, slightly enlarged.

METACYPRIS FORBESII.

Figs. 22, 23, and 24. Dorsal, ventral, and lateral views of an example of the more common form; much enlarged.
Figs. 25 and 26. Lateral and dorsal views of another associated form, probably only a variety; much enlarged.



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